Investigations of passive flow control devices for wave drag reduction

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Contents

INCAS presentation

Main Location : Bucharest, Iuliu Maniu 220
Secondary Location : Maneciu, Prahova district
New Location(s) for special activities

INCAS presentation

Profile :

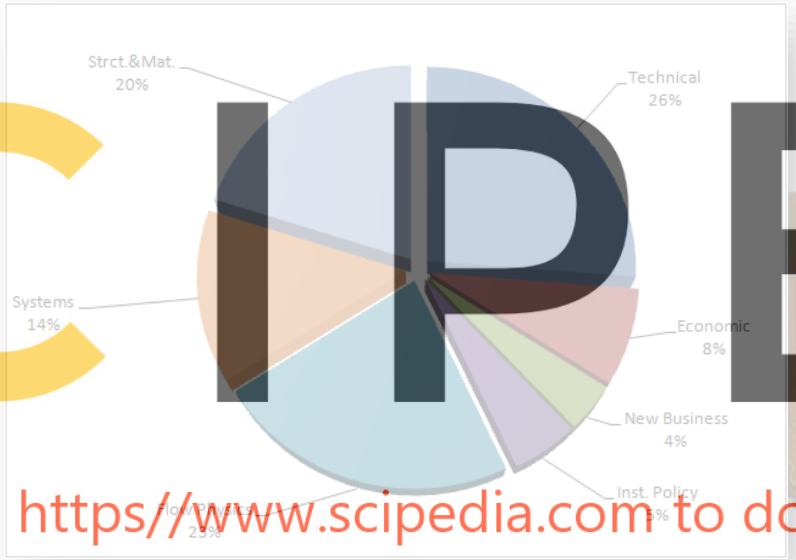
- State owned company/ Public body
- Founded in 1949
- Leading research establishment for aerospace research in Romania

Major activities :

- ✓ Main design authority and system integrator in aeronautics
- ✓ Aerodynamic design
- ✓ Structural design and analysis
- ✓ Experimental wind tunnel validation
- ✓ Global performance analysis

- ✓ Atmospheric investigations
- ✓ Earth Observation

❖ Research and development in aeronautics and aerospace sciences



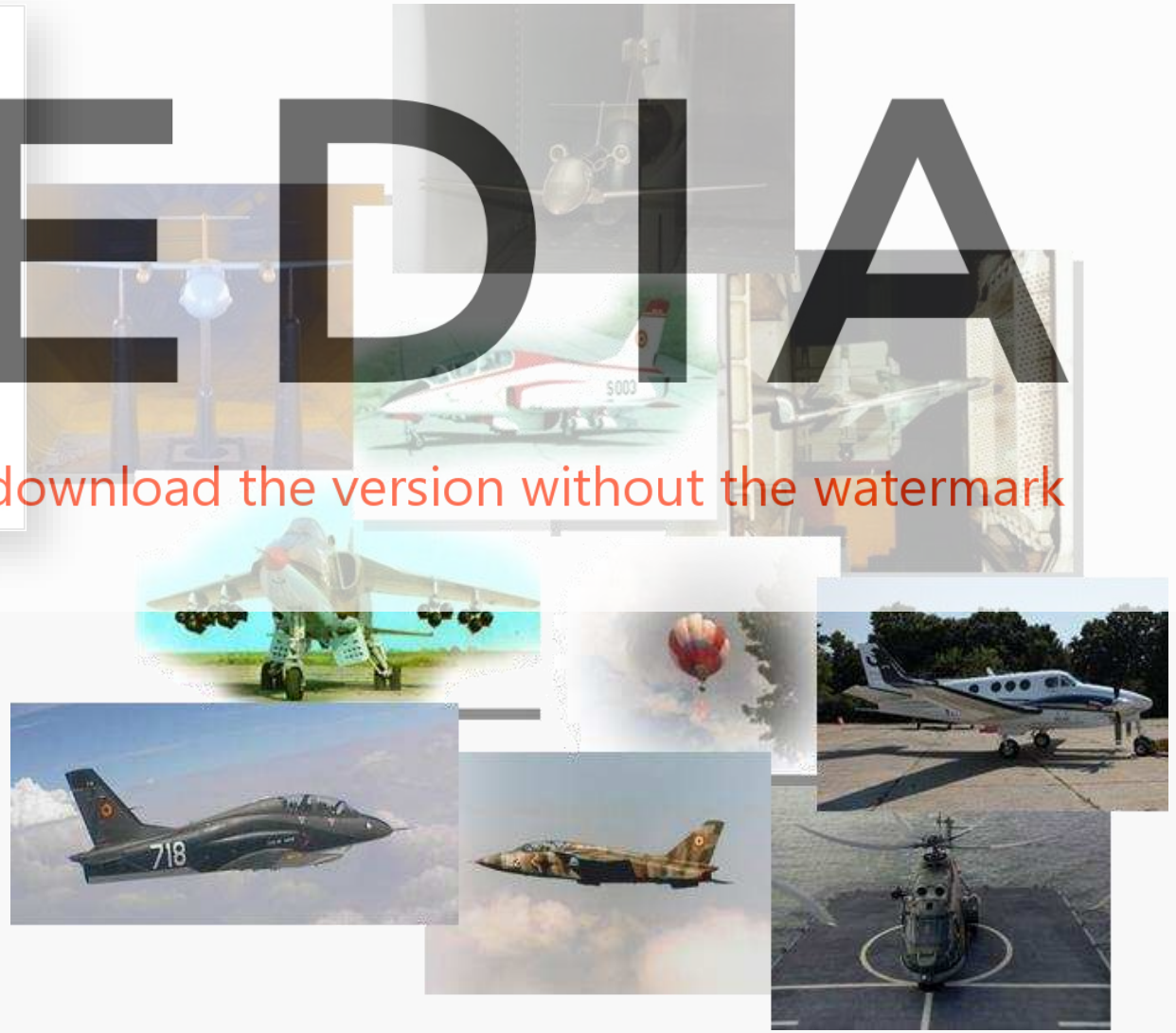
INCAS Personnel Structure

Total positions - 218
R&D positions – 126

Total researchers – 106
Where :

PhD – 21
PhD students – 14

PhD leaders - 3



INCAS presentation

Subsonic Wind Tunnel

- Atmospheric pressure, continuous type facility
- Maximum speed : 110 m/s
- 2.5m x 2.0m x 4m test section
- Usual Reynolds number up to 1.5 million.

Equipment:

- Traditional closed circuit type
- Solid walls test section
- External 6 component pyramidal type balance
- Standard pressure acquisition systems
- New data acquisition technologies
  - Hot film/wire measurements
  - IR camera
  - PIV system
  - 3D dynamic deformation – fast cameras
- Laser visualization systems
- CTS system – open/closed loop operation
- Aeroacoustics and airframe noise evaluation
  - 72 microphone matrix system
  - Beamforming technology
  - Cross-corelation with dynamic pressure/kulites

INCAS presentation

Supersonic Wind Tunnel

- blowdown type
- 1.2m x 1.2m test sections (3D)
- Mach number range : 0.1 … 3.5
- Reynolds number up to 100 millions/m
- Max test run duration : 90 sec.
- Max pressure : 16 bar (settling chamber)

- Interchangeable porous transonic test section
- Variable porosity from 0.01% up to 9%
- Interchangeable complex 3D/2D 0.8m x 1.2m test section
- Active model/combustion capability

Equipment:

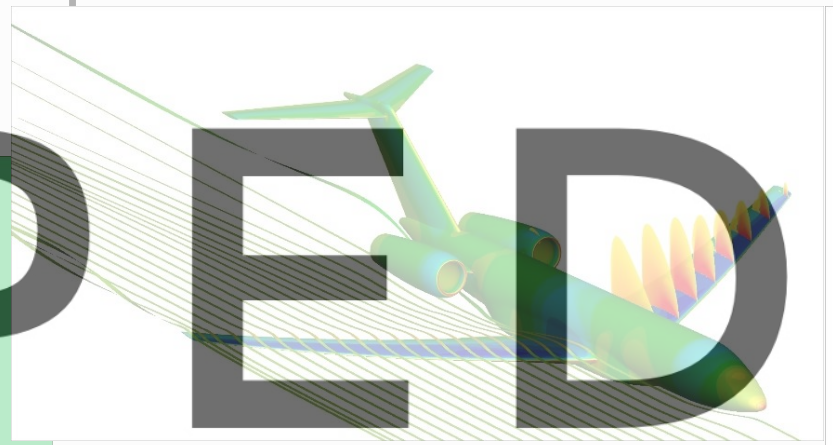
- Sting mounted, internal balance
- Pressure measurements
- Mach control system
- CTS system
- 800 mm schlieren system
- PIV under development
- IR camera
- ultra fast digital camera

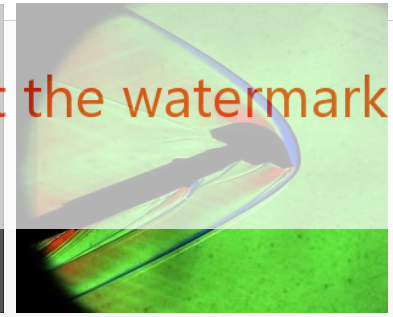
CFD Lab

INCAS presentation

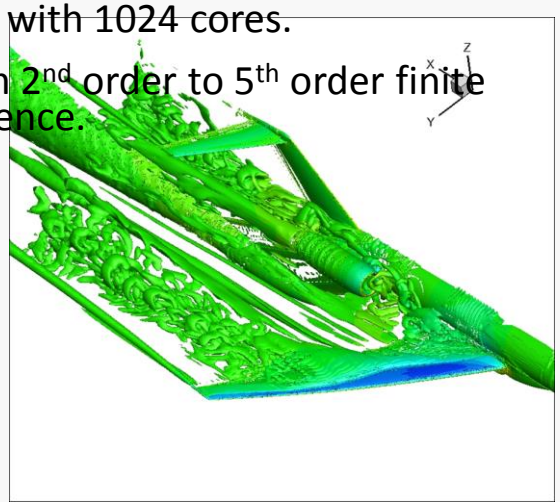
National Institute for Aerospace Research "Elie Carafoli"

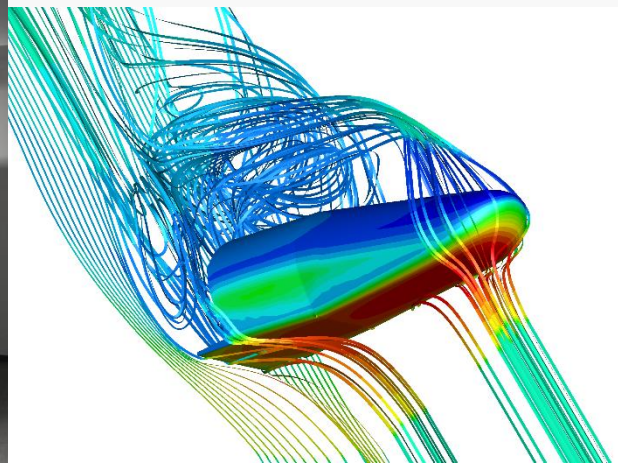
- SGI UV-2000 :
  - 528 cores (Intel Xeon E5-4627v2)
  - 8.4 TB RAM (shared memory)
  - 42 TB for storage / 30 TB for users.
  - 12 Intel Phi
  - 4 NVidia Quadro 6000
  - Linux - SuSe.
- SuperMicro:
  - 160 cores
  - 320 GB RAM (distributed memory).
  - Windows.
- Beowulf:
  - 48 cores
  - 512 GB RAM (distributed memory).
  - Windows.





- Ansys Fluent and CFX with 272 cores.
- Numeca Fine/OPEN with 1024 cores.
- In-house codes from 2nd order to 5th order finite volume/finite difference.





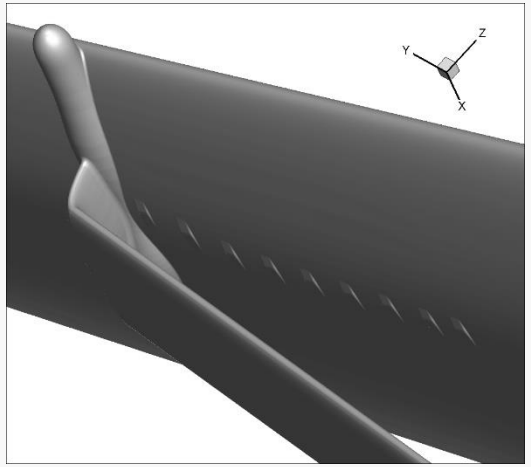
Introduction

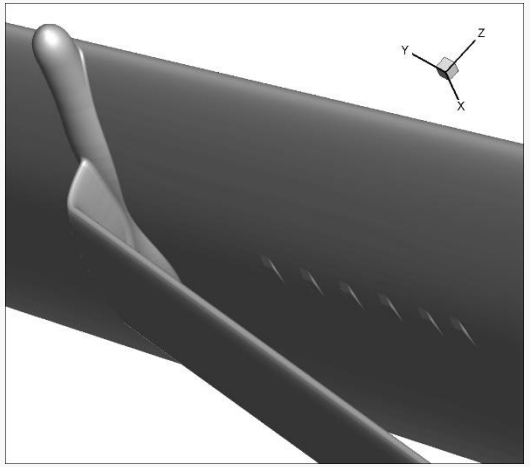
Three methods for reducing the drag associated with the presence of strong shocks have been investigated:

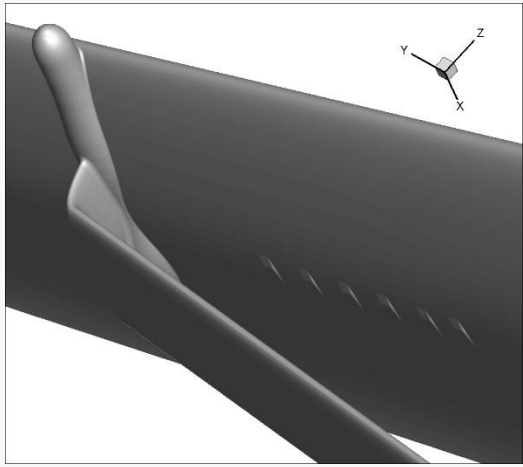
1. Kuchemann's Carrot

2. Shock Control Bumps

3. KC + SCB (v0, v1 ,v2)





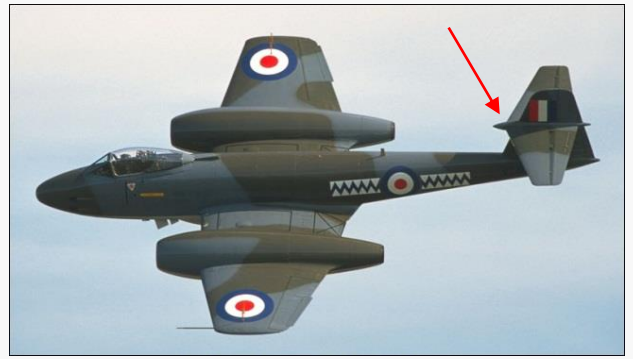


Introduction

Kuchemann's Carrot:

- Positioned at the wing-strut junction – Local effect
- Below the wing's leading edge not to affect the suction side
- "Fuselage-waisting" at the strut's maximum thickness
- Improves the "area-rule"
- Used on a number of aircrafts from the past:
  - ✓ Tu 134
  - ✓ Hawker Sea Hawk
  - ✓ Blackburn Buccaneer
  - ✓ Gloster Meteor

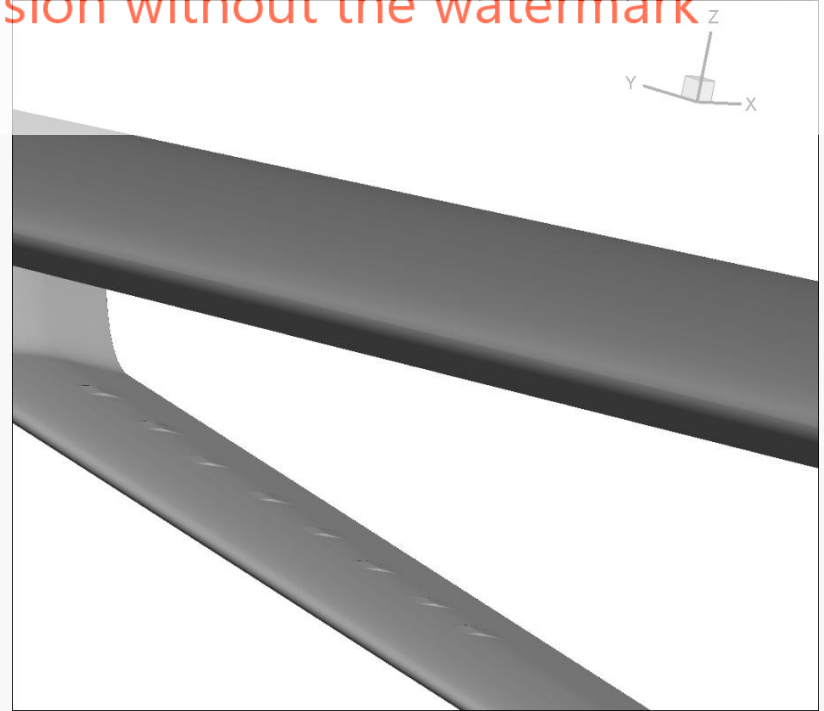
- No numerical optimization used



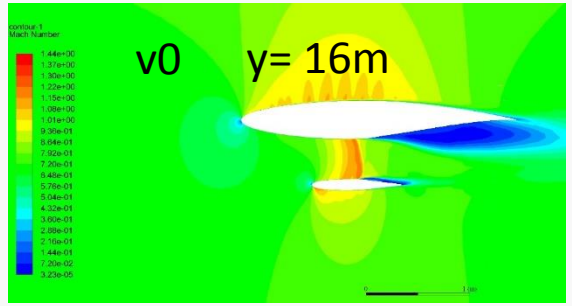
Introduction

Shock Control Bumps:

- Positioned on the wing's pressure side and the strut's suction side, placed at 0.25m distance from each other – Distributed effect
- Not on the vertical strut
- Generally they have been observed to reduce drag in transonic flows where Mach number exceeds 1.3 – applicable in this case
- 3D wedge type geometry with rounded sides
- Height on the wing is roughly 70% of the boundary layer thickness
- Height on the strut is around 95%.
- The height of the bump is determined from 2D analyses at three span wise locations of 15, 15.5 and 16m
- Extended tail, flat top, a width to height ratio of approx. 9 and a length to width ratio of 4
- No numerical optimization used
- "Review of research into shock control bumps" - Shock Waves-2015, P. J. K. Bruce · S. P. Colliss

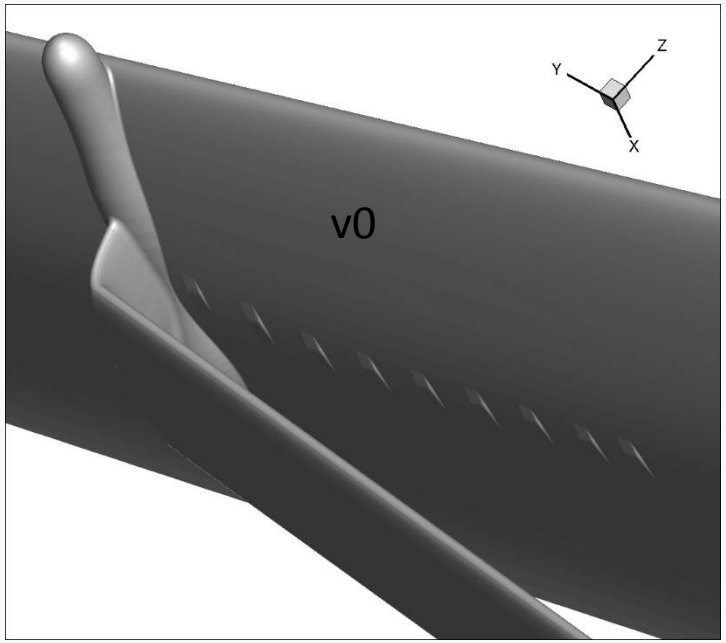


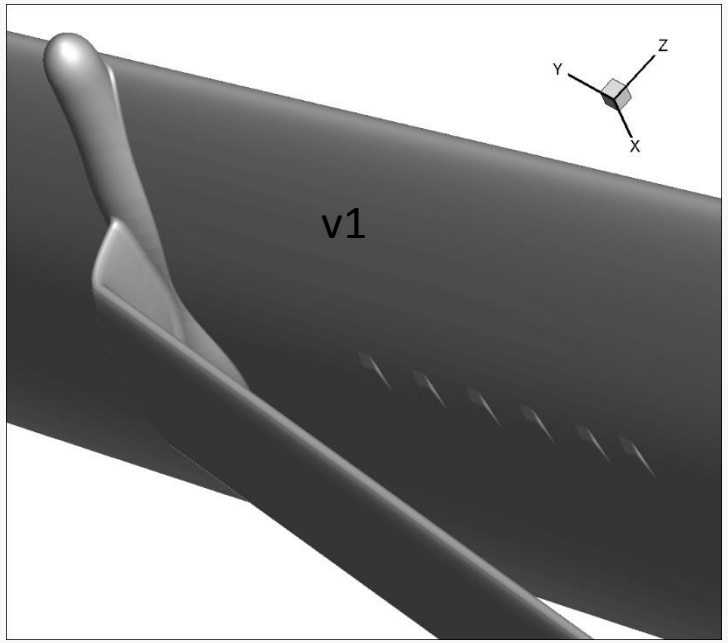
Introduction

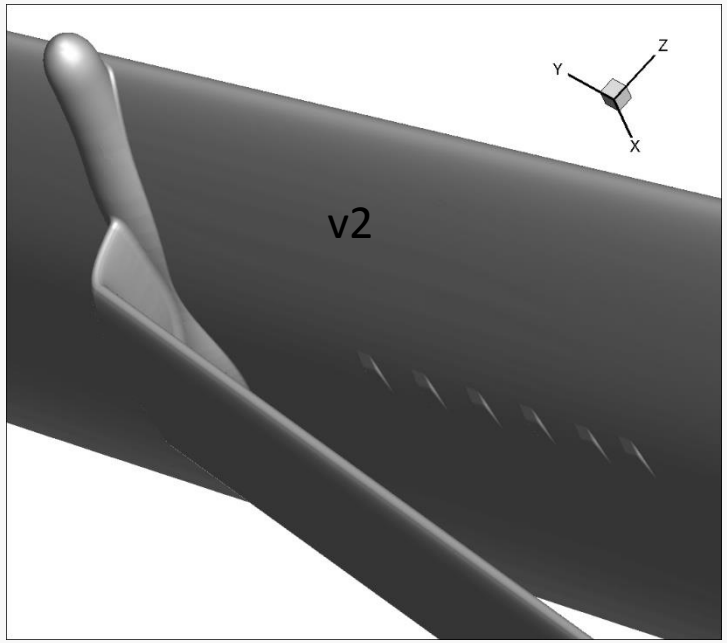


Kuchemann's Carrot + Shock Control Bumps:

- Local effect of the KC + distributed effect of the SCB
- KC shape taken from previous model
- SCB shape taken from previous model
- SCBs repositioned (according to the shock position) and reduced in number due to massive flow detachment at y= 16m.







Mesh & Solver

Solver - Ansys Fluent v18.0:

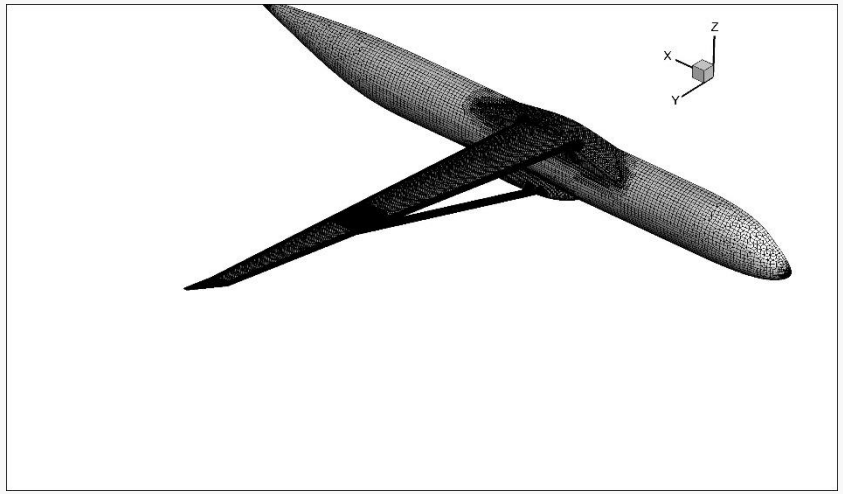
- density based solver
- Roe Scheme
- second order upwind with Barth – Jespersen slope limiter (1989)
- Modified 3 equation version of the **k-ω SST** turbulence model with several enhancements:
  - ✓ **Curvature correction** for the modeling of turbulence production (Smirnov & Menter, 2008)
  - ✓ **Compressibility effects** for the modeling of turbulence dissipation (Sarkar & Balakrishnan, 1990)
  - ✓ **Production Limiter** to limit the excessive generation of turbulence energy at stagnation points (Menter, 1994 + Kato & Launder, 1993) – standard practice for transition models
  - ✓ (the 3rd equation is for the) **Intermittency transition model** (Menter & Langtry, 2004) with **crossflow instability** (Arnal, 1984) to avoid Wilcox's - Low-Reynolds correction

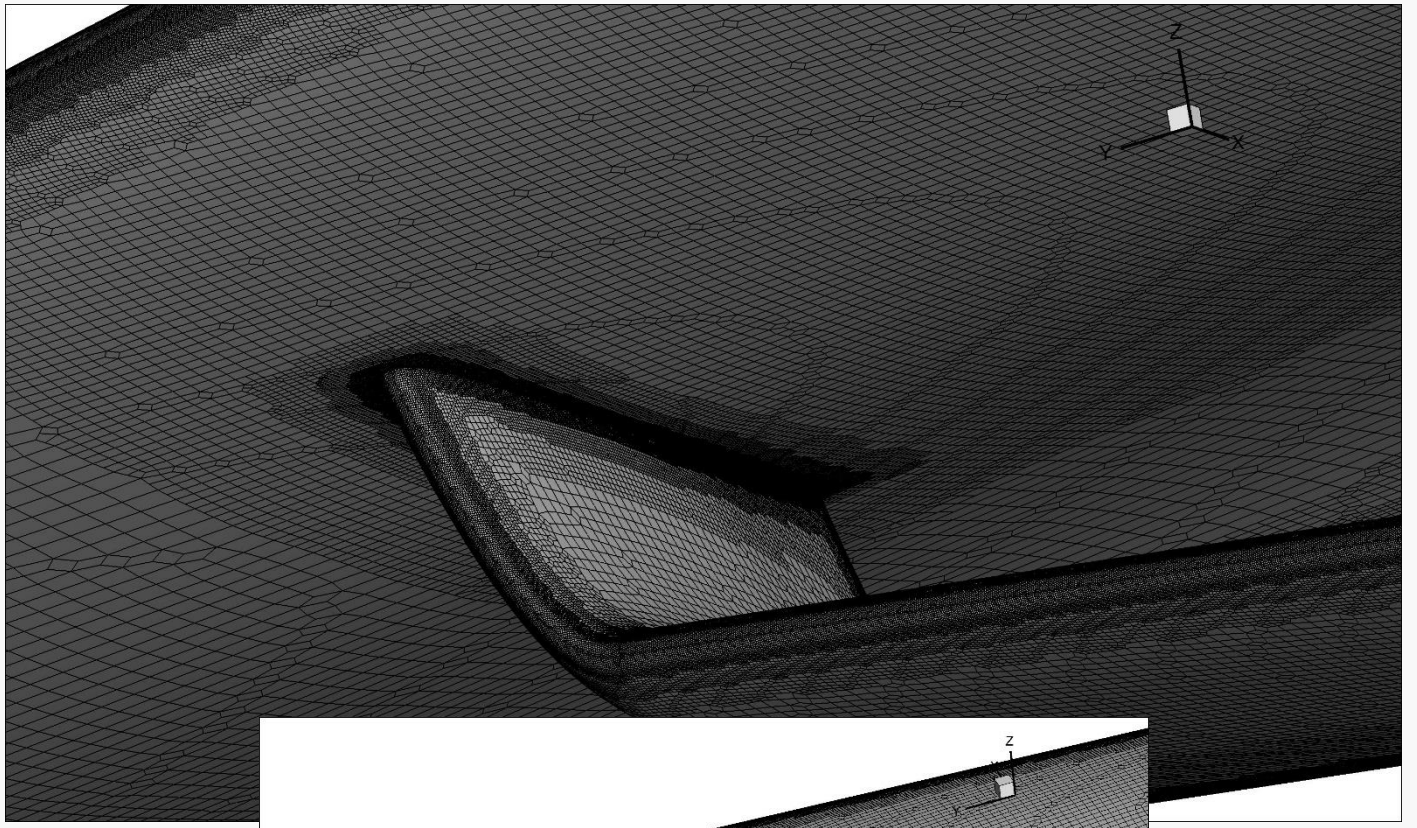
Mesher – Numeca Hexpress

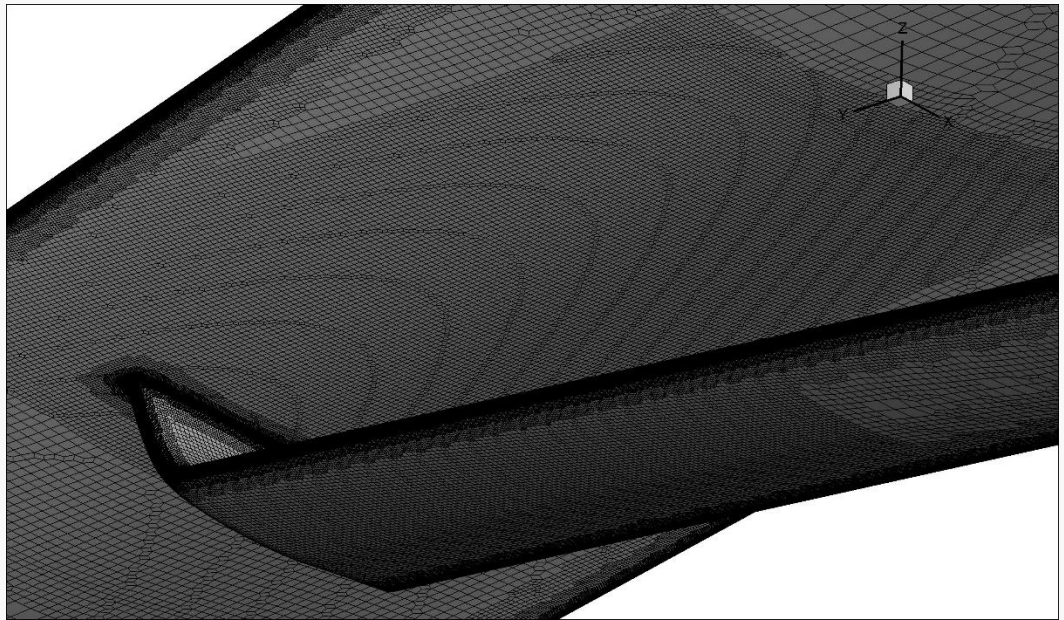
- Unstructured roughly 95M cells each configuration for the semi-span model.
- Full-hexahedral / cut-cell type
- Inflation layer: Y+ < 1 and growth rate = 1.15
- 6 cells on the trailing edge
- Refinement region in the wing-strut region from y=14.5m to y=17m
- Good control of mesh sizing from one geometry to another

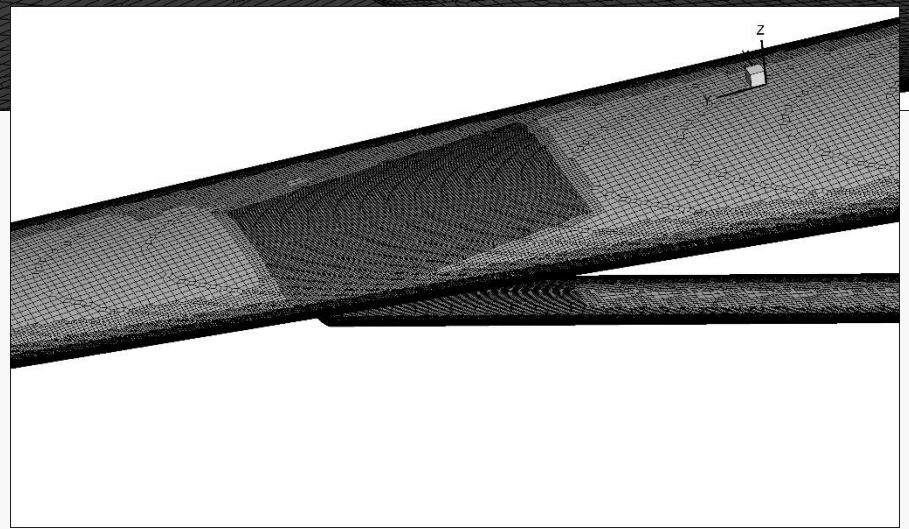
Mesh & Solver

Base



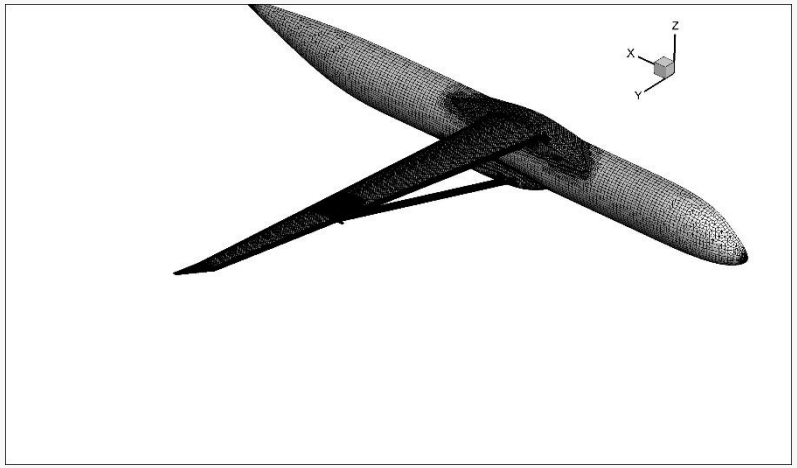


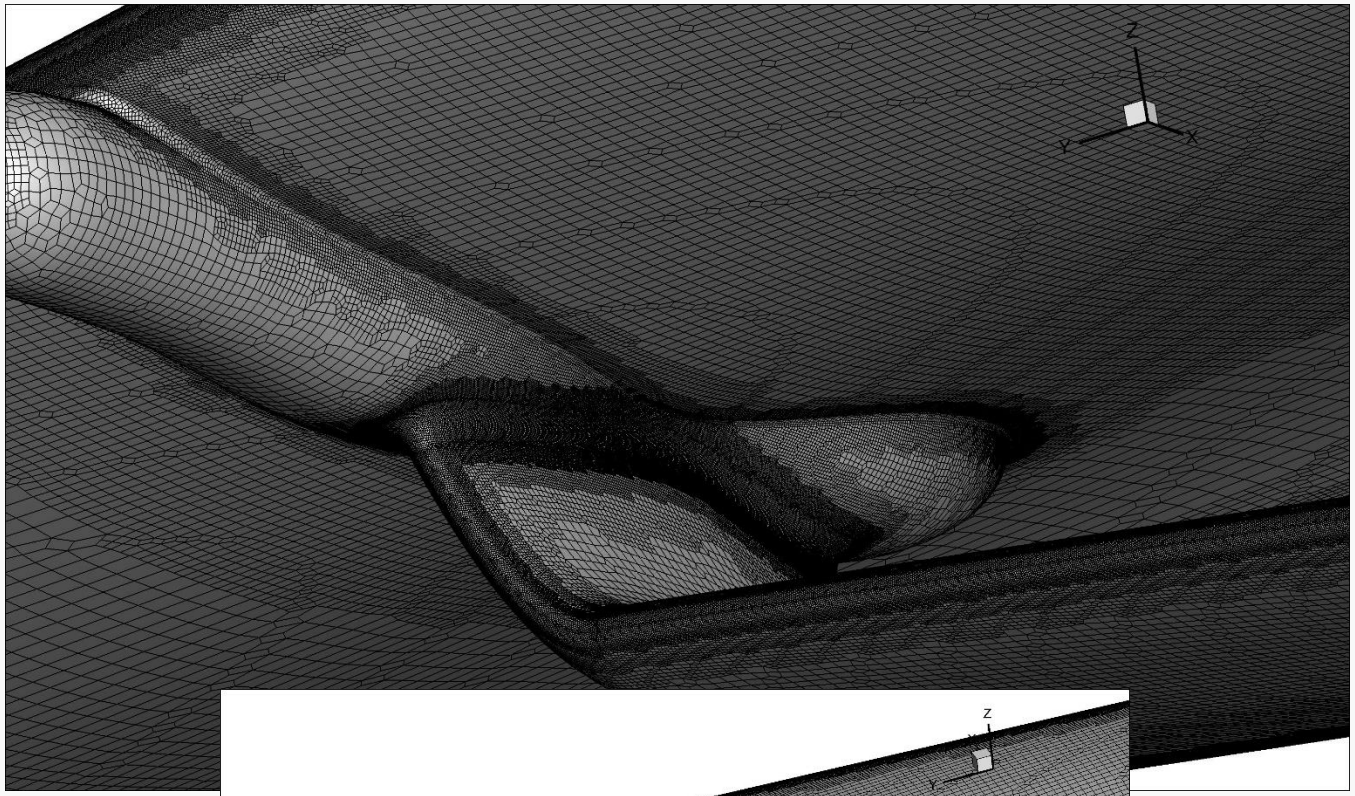


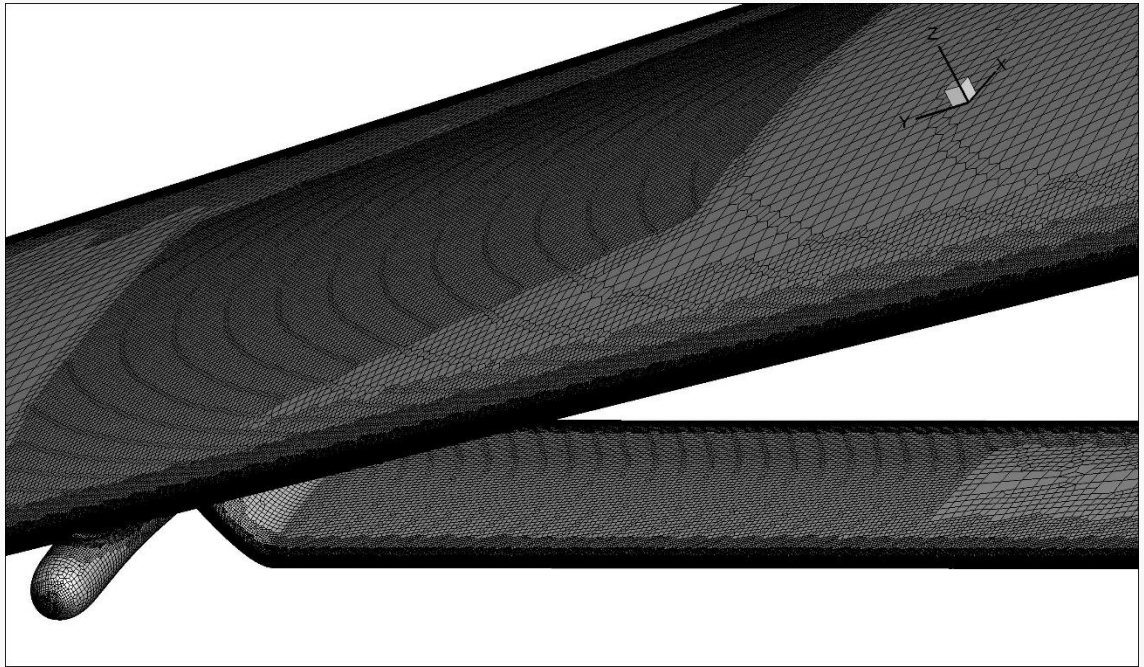


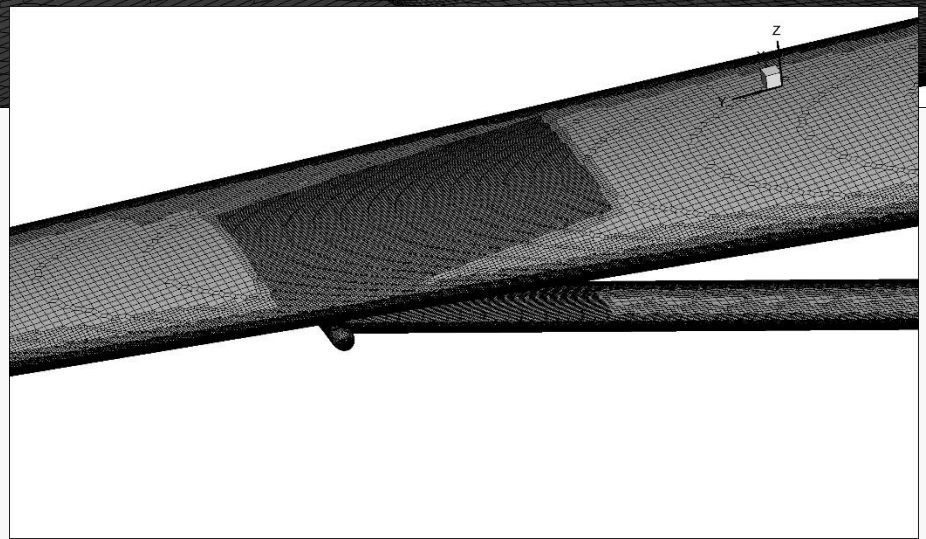
Mesh & Solver

KC



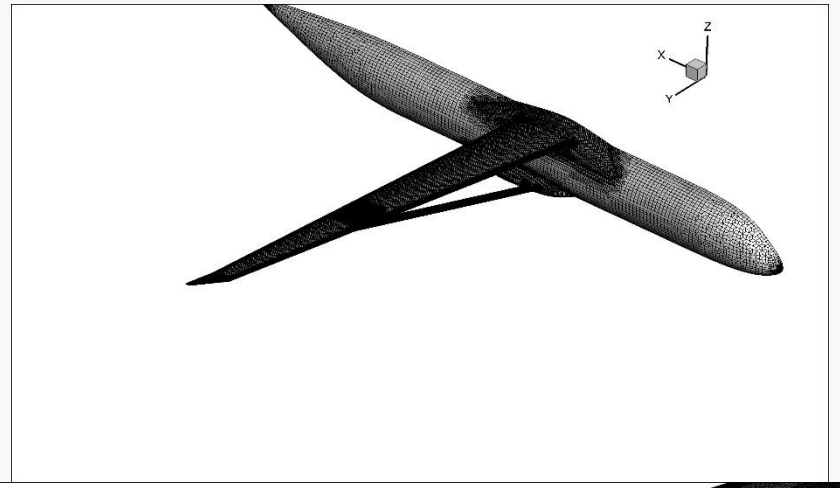


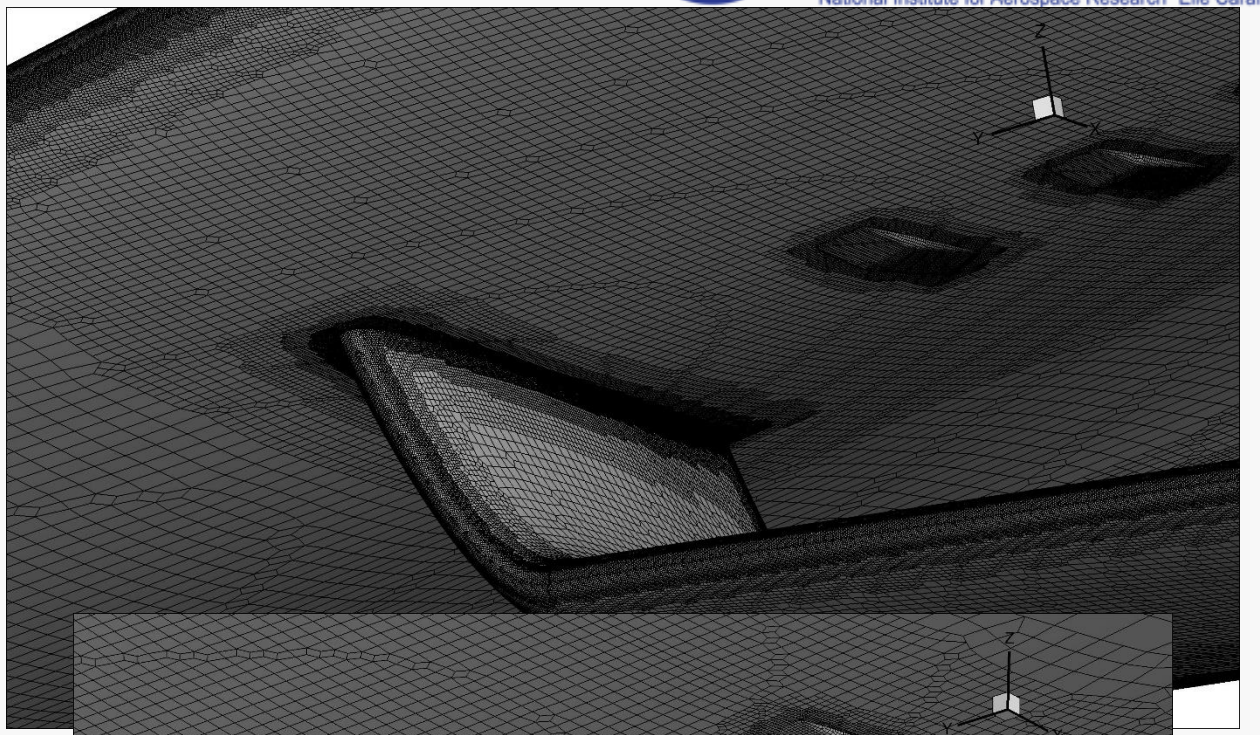


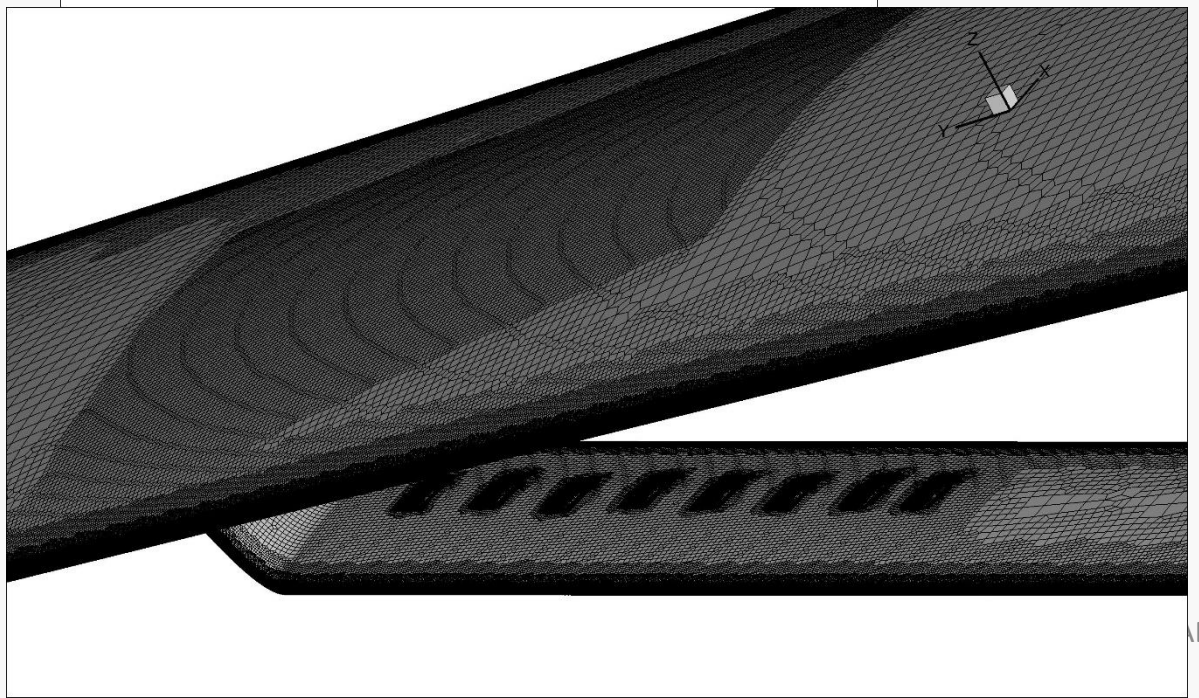


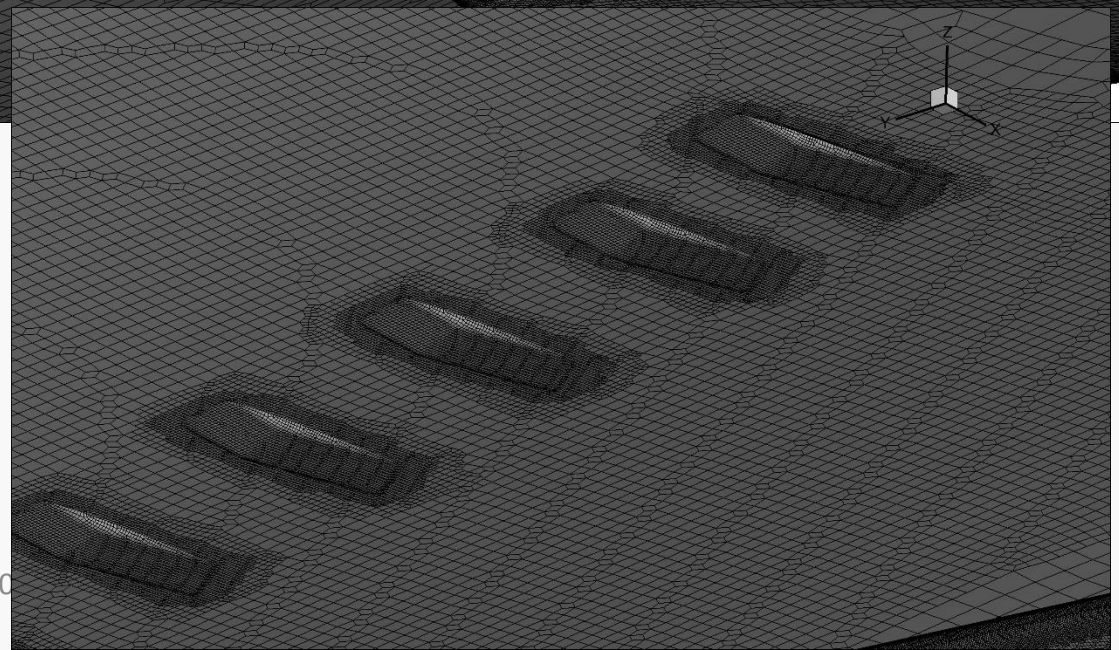
Mesh & Solver

SCB









Results

The flow conditions are summarized as:

- Mach 0.72, angle of attack 1^o
- Cruise altitude 30000ft on an atmosphere ISA+0 with:
  - pressure 30089.59 Pa,
  - temperature 228.71K.
- The reference area is S = 80.5 m^2,semi-span model
- The reference length is 3.264m.

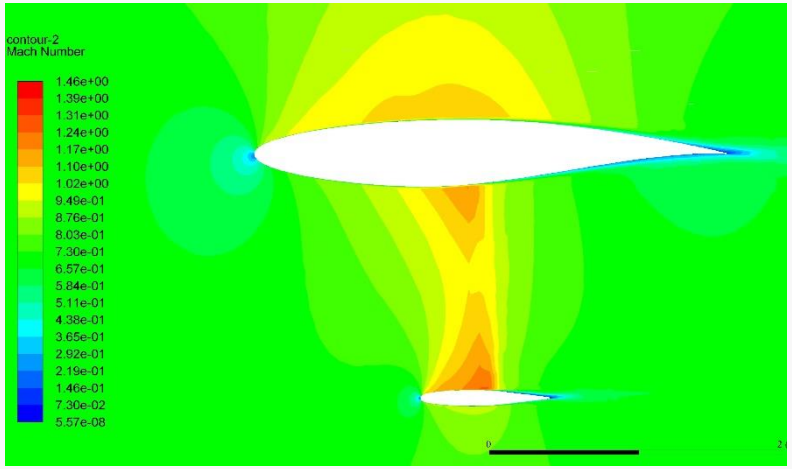
Configuration	Lift	Drag	L/D	aoa
Base	**0.383**	**0.02281**	**16.77208**	**1**
KC	0.385	0.02278	16.91656	1
SCB	0.379	0.02269	16.69289	1
KC_Lift_match	**0.383**	**0.02274**	**16.83658**	**0.98**
SCB_Lift_match	**0.383**	**0.02275**	**16.84163**	**1.03**
kc_scb_v0	0.386	0.02310	16.72154	1
kc_scb_v1	0.383	0.02296	16.68633	1
kc_scb_v2	0.383	0.02289	16.72369	1

Drag breakdown:

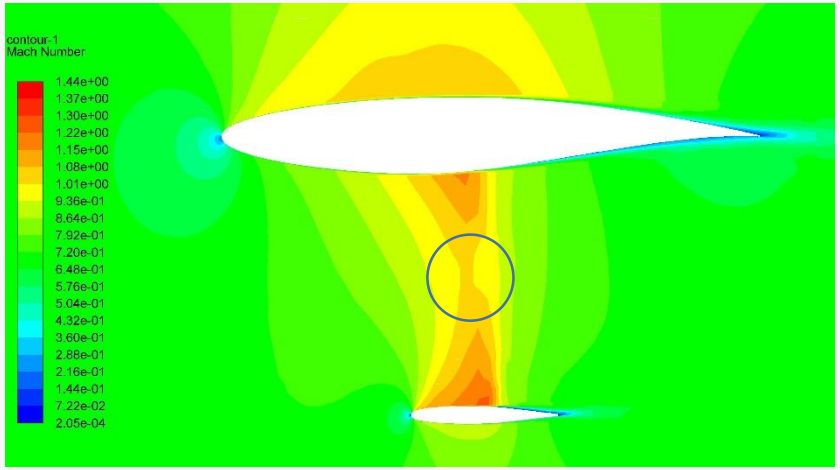
Configuration	pressureDrag	viscousDrag	delta_visc	delta_pres
Base	**0.01173867**	**0.01107338**	--	--
KC	0.011690303	0.01108774	-1E-05	5E-05
SCB	0.011646659	0.01104708	3E-05	9E-05
KC_Lift_match	**0.011652629**	**0.01108774**	**-1E-05**	**9E-05**
SCB_Lift_match	**0.011700992**	**0.01104617**	**3E-05**	**4E-05**

Results

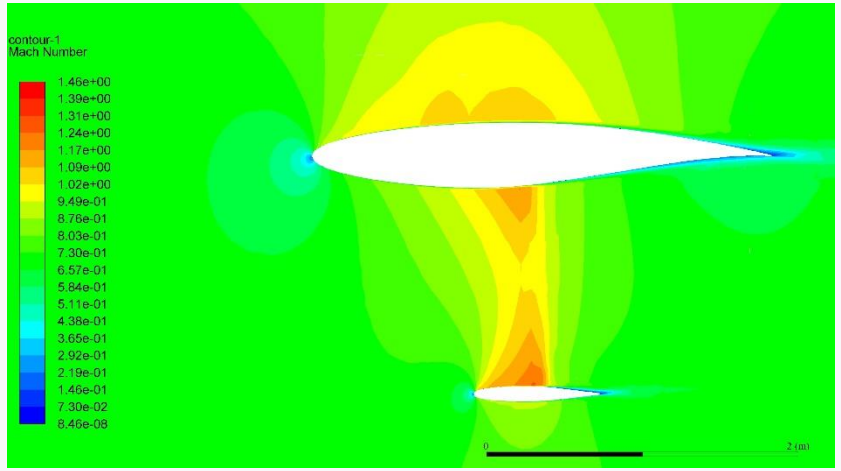
Baseline



Kuchemann Carrot

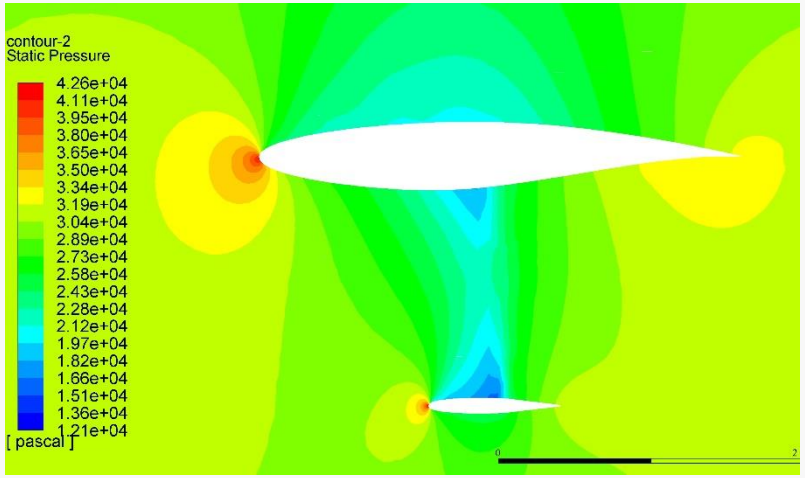


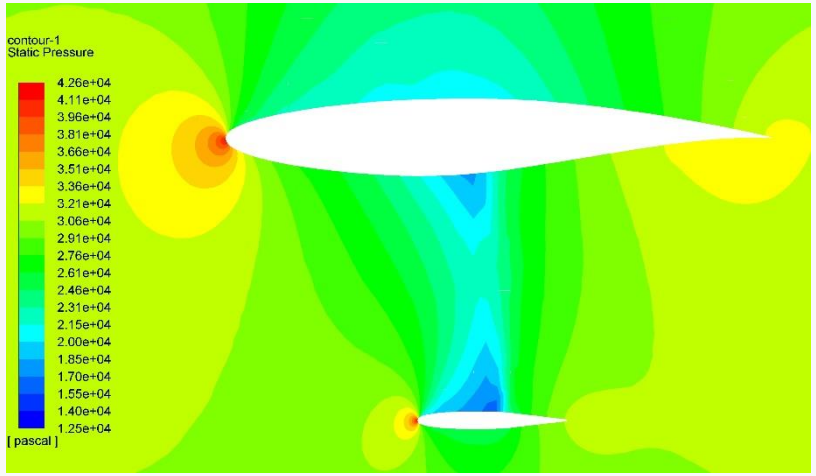
Shock Control Bump

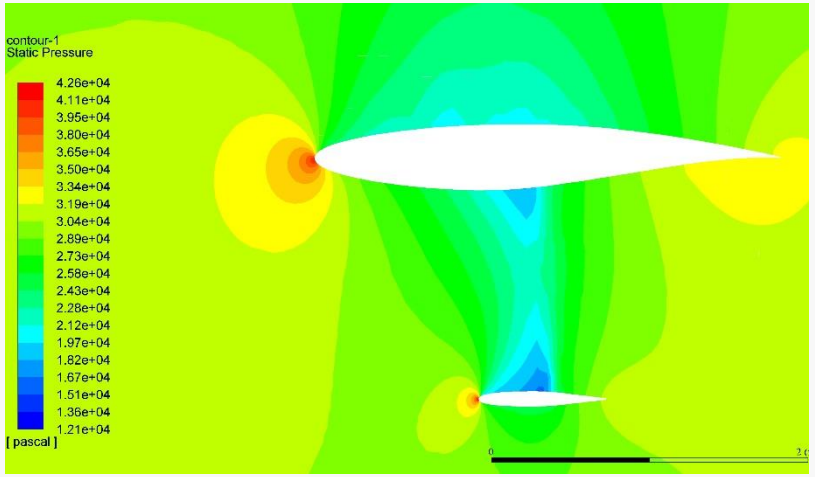


Y slice =12m

Little / No difference

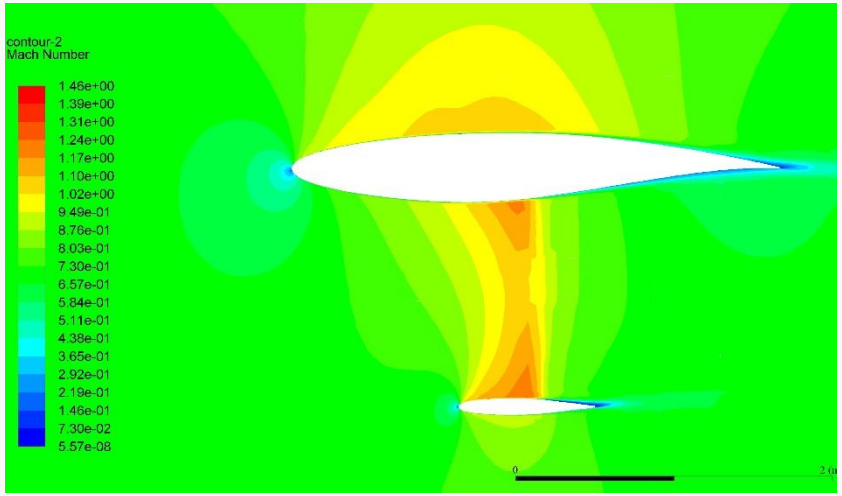




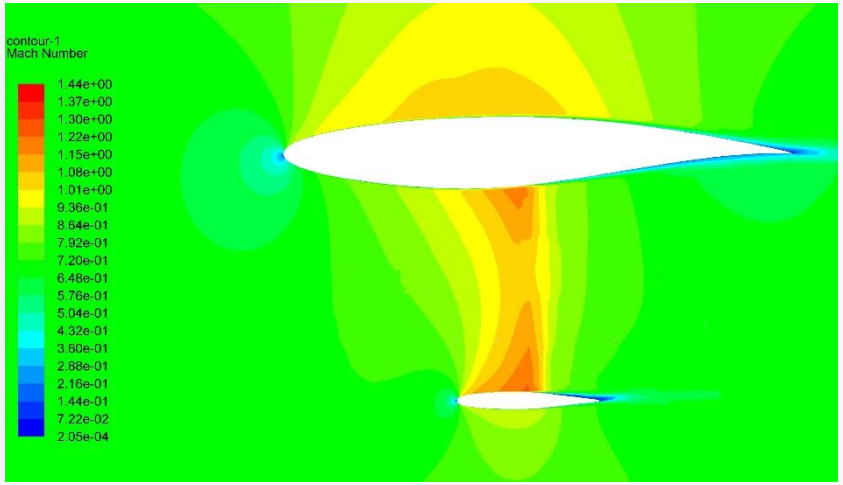


Results

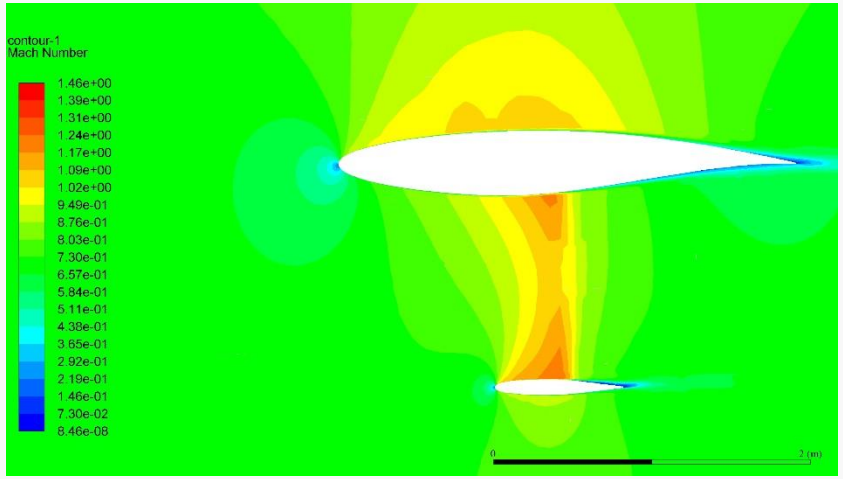
Baseline



Kuchemann Carrot

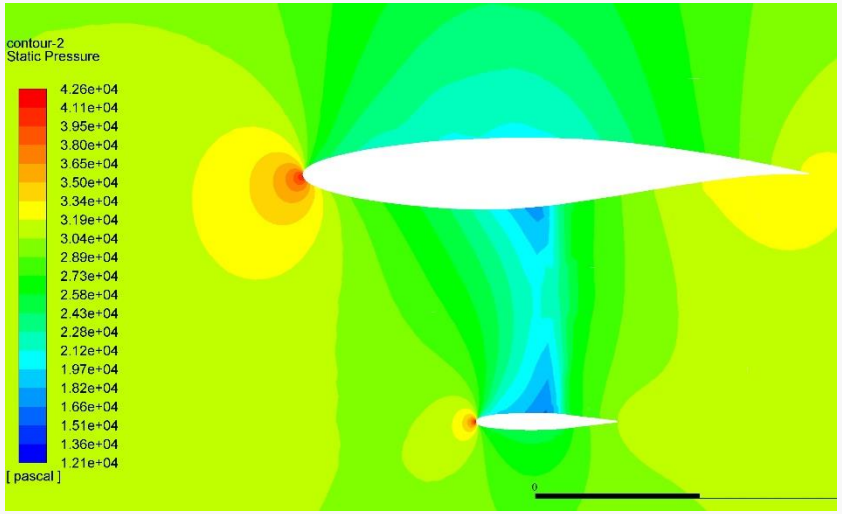


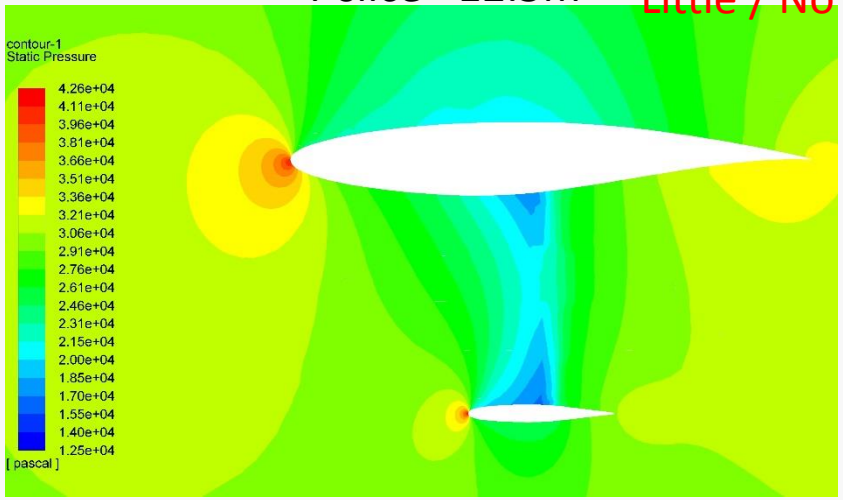
Shock Control Bump

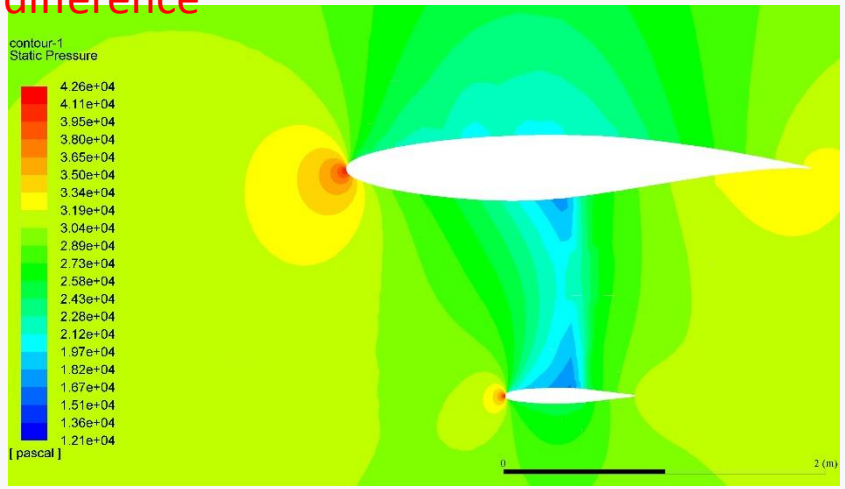


Y slice =12.5m

Little / No difference

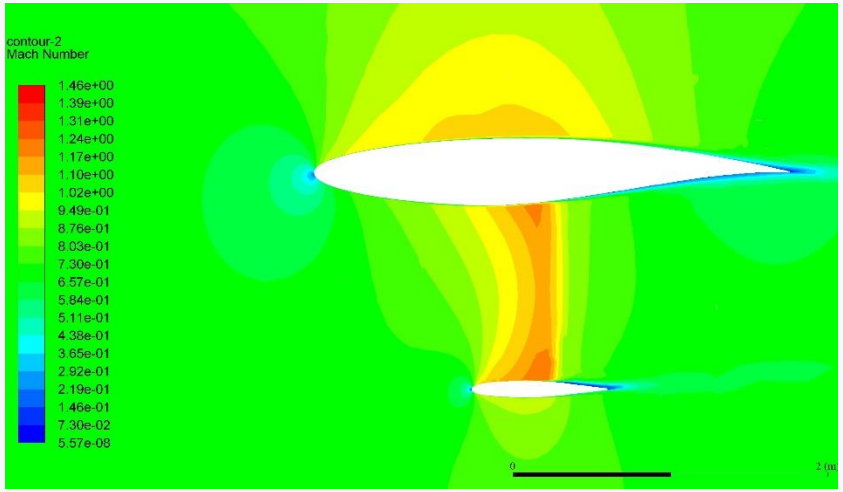




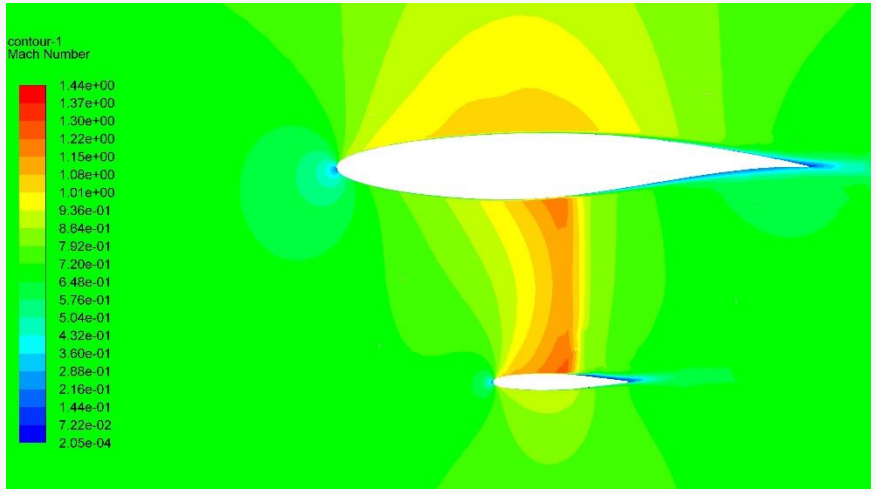


Results

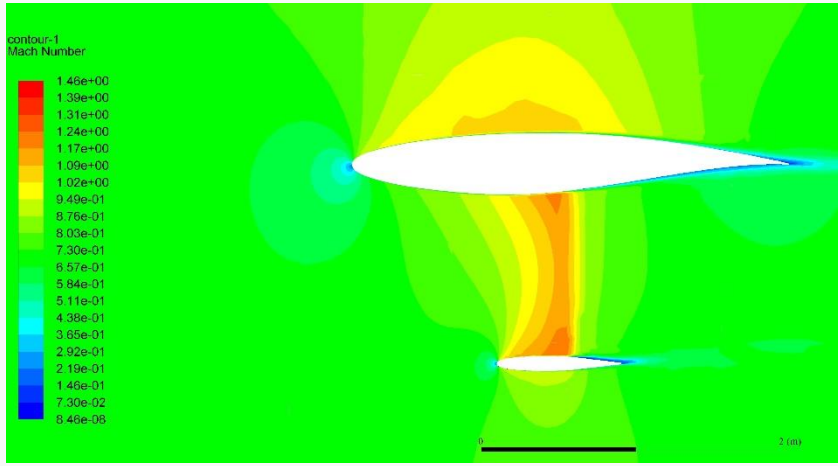
Baseline



Kuchemann Carrot

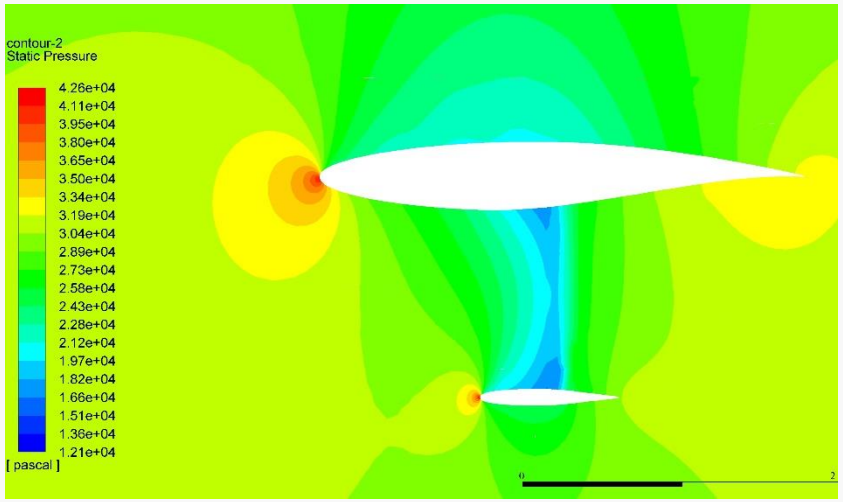


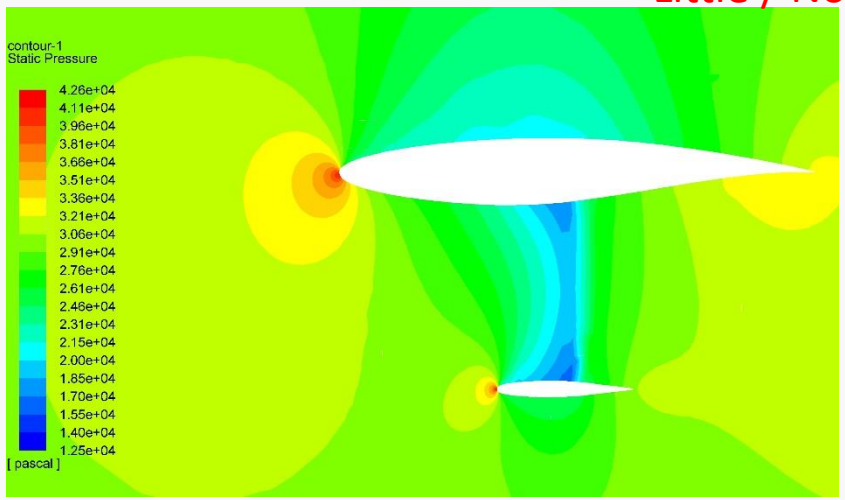
Shock Control Bump

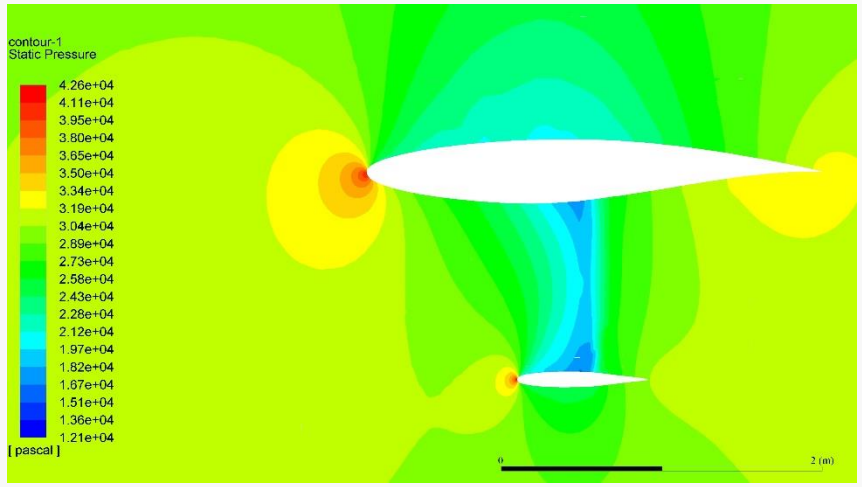


Y slice =13m

Little / No difference

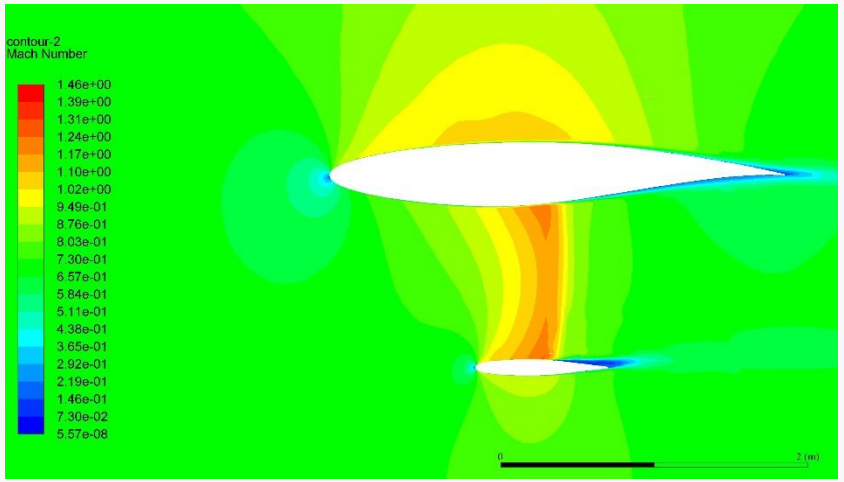




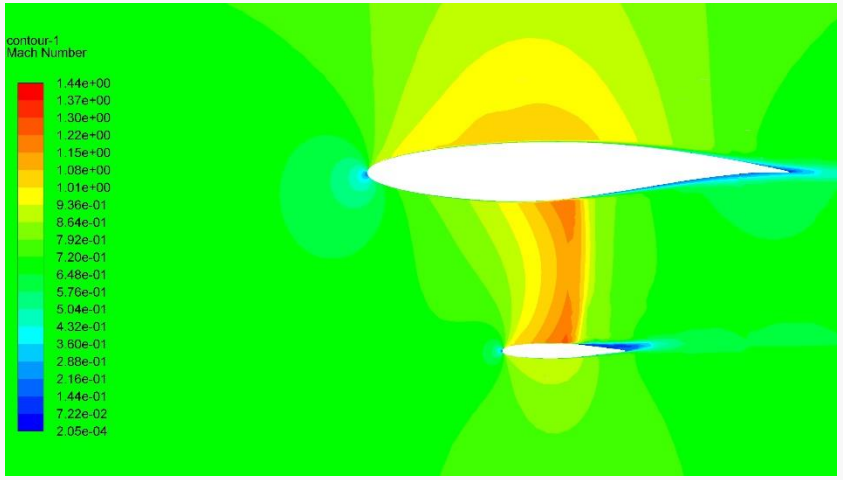


Results

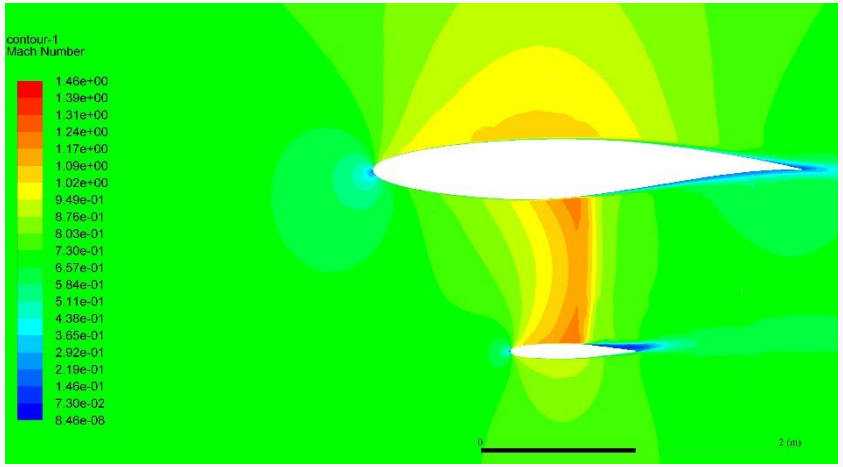
Baseline



Kuchemann Carrot

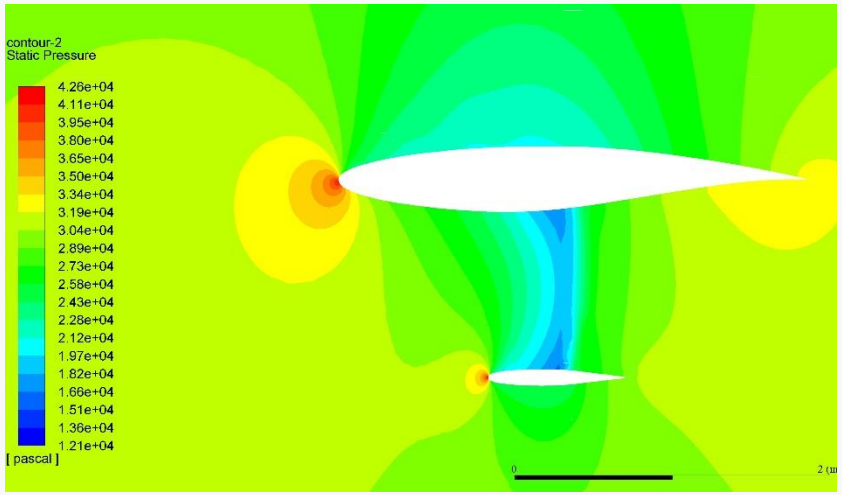


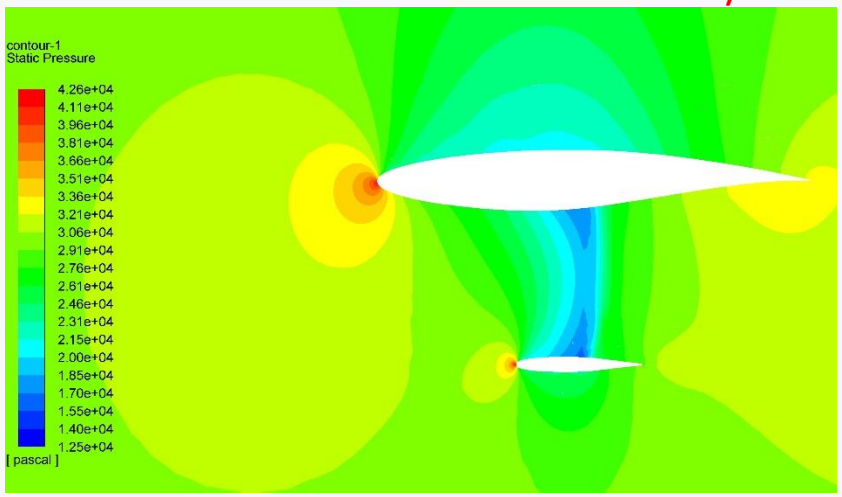
Shock Control Bump

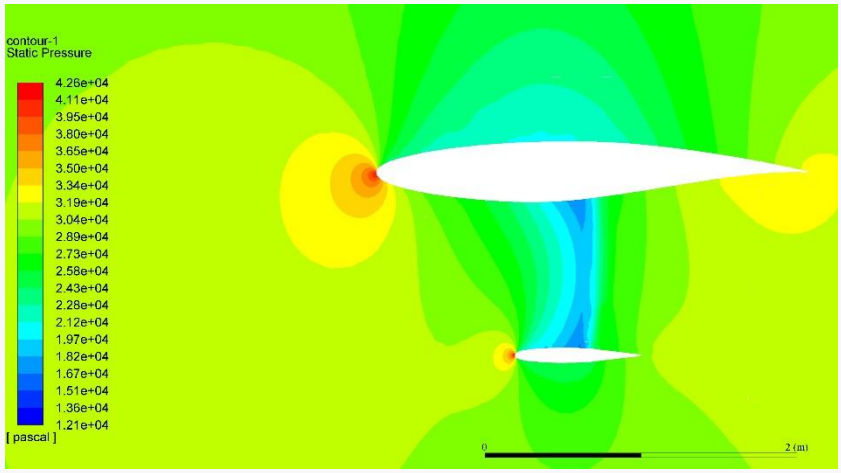


Y slice =13.5m

Little / No difference

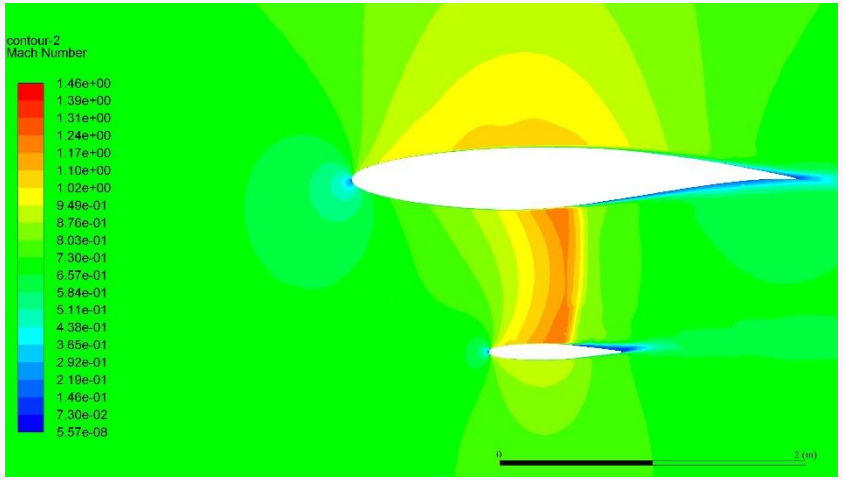




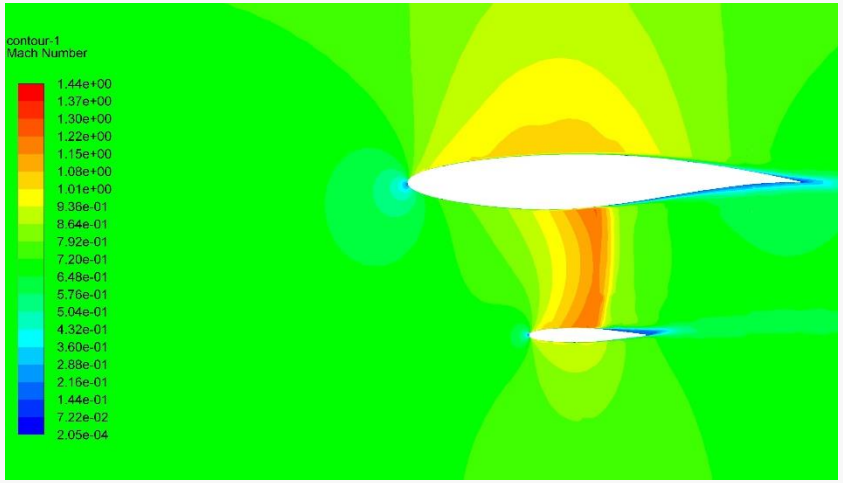


Results

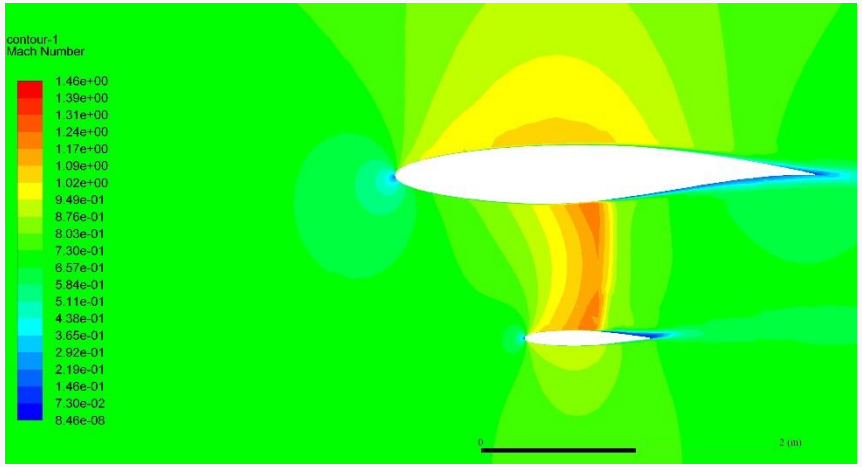
Baseline



Kuchemann Carrot

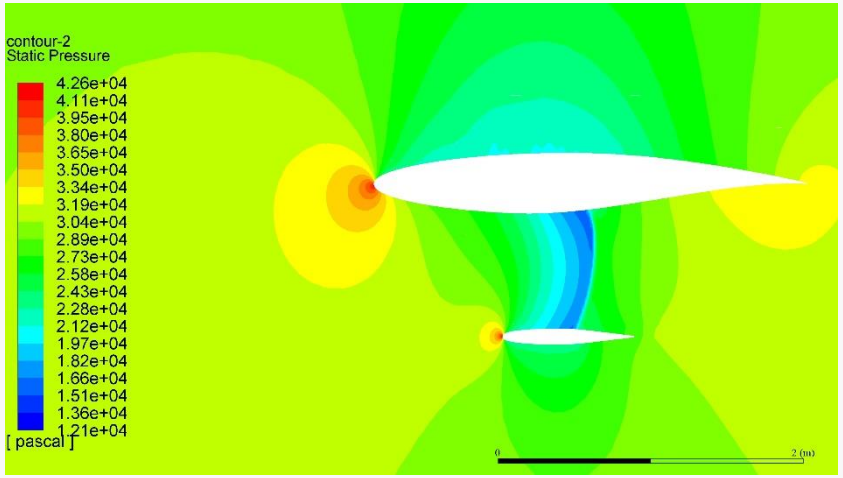


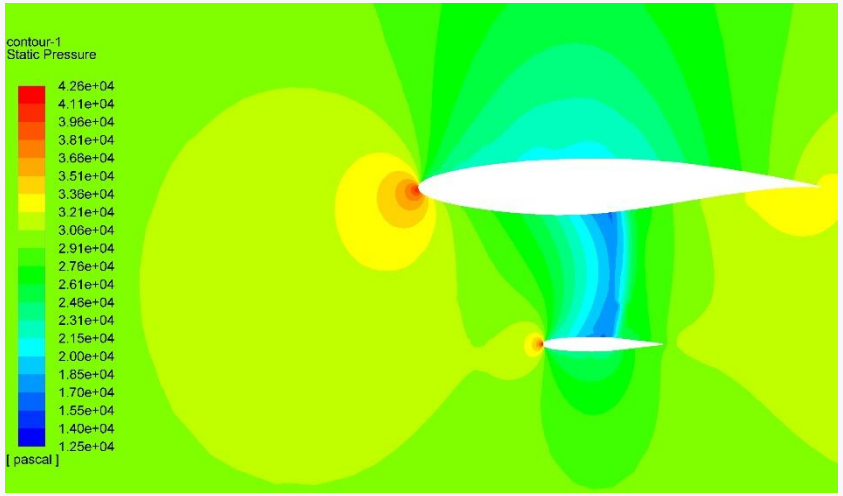
Shock Control Bump

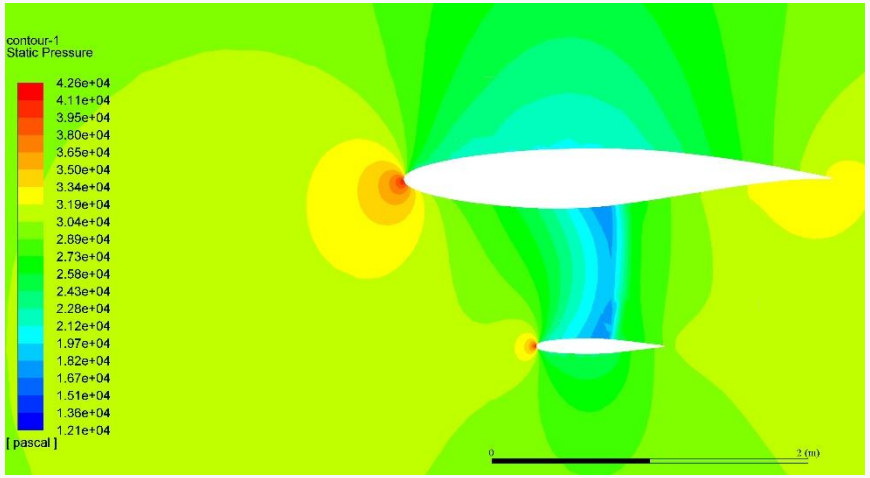


Y slice =14m

Little / No difference

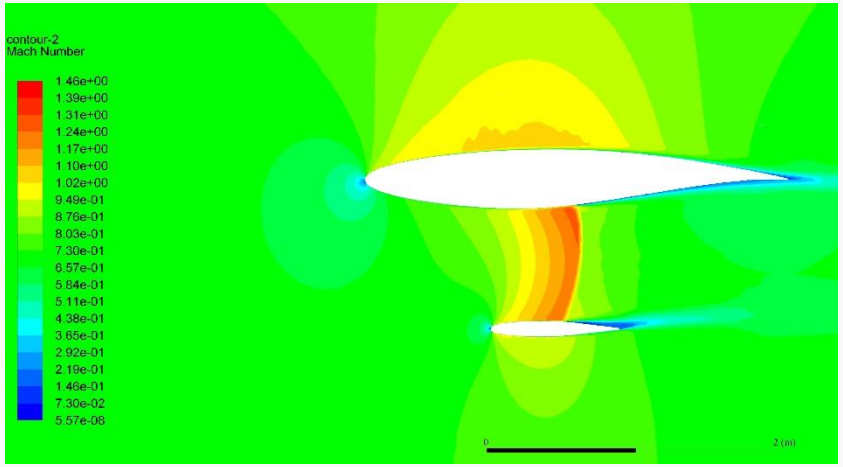




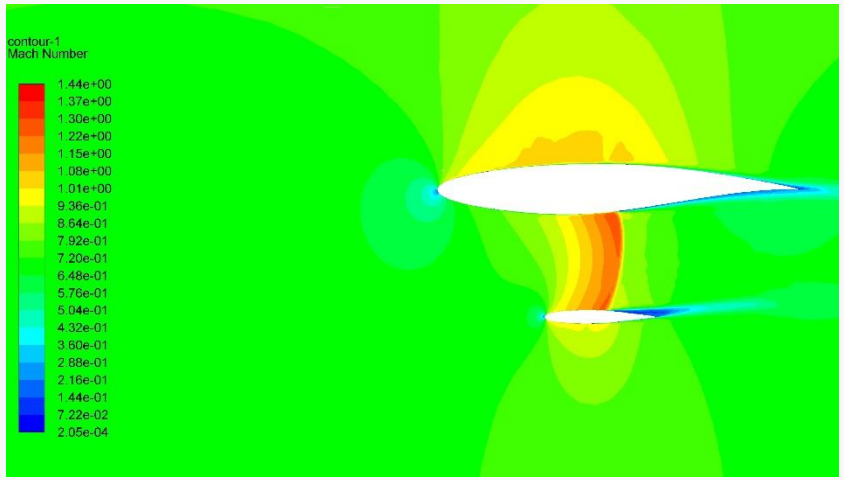


Results

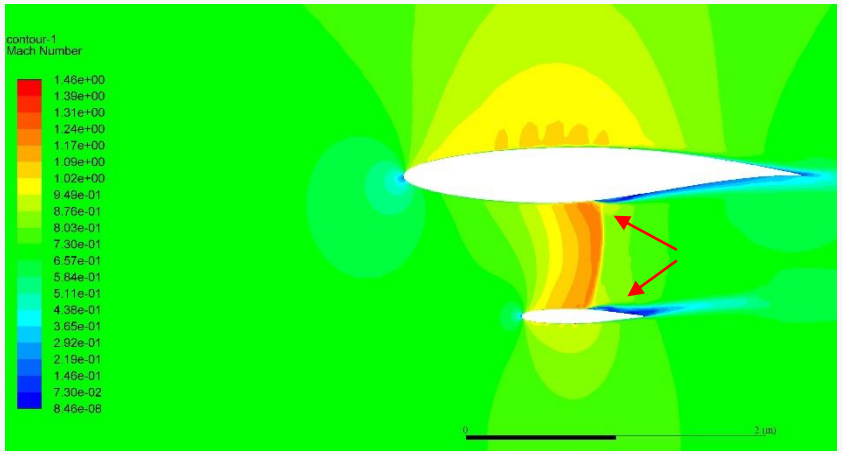
Baseline



Kuchemann Carrot

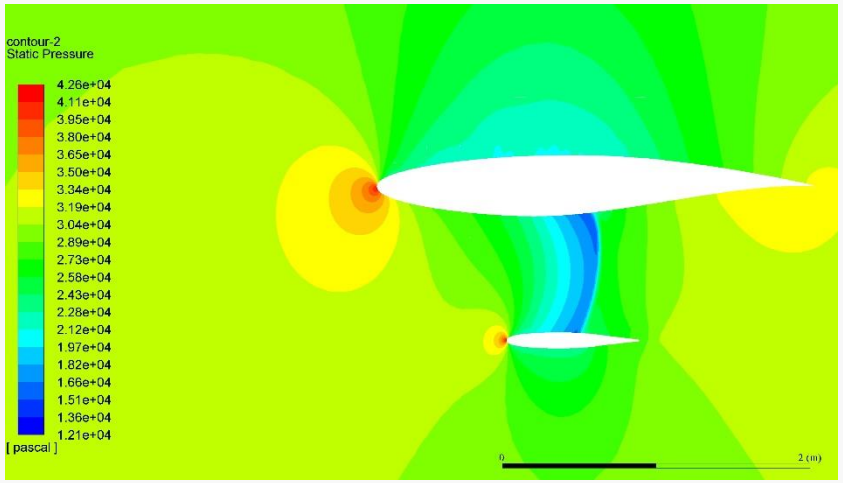


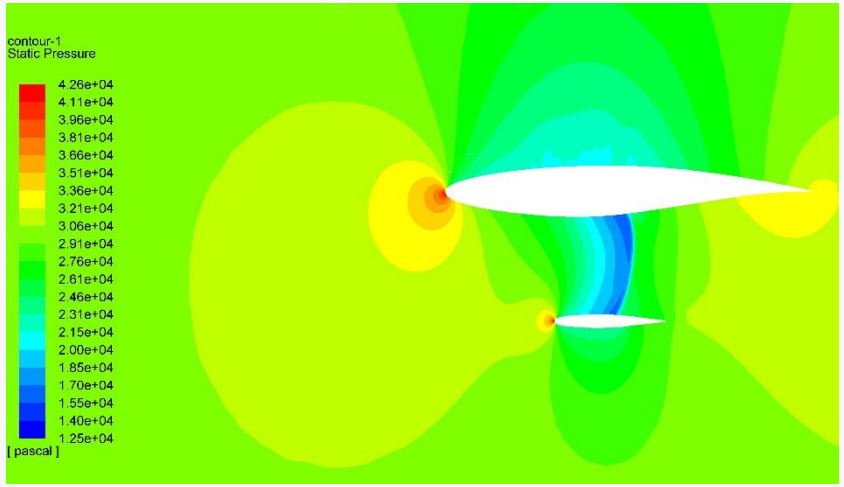
Shock Control Bump

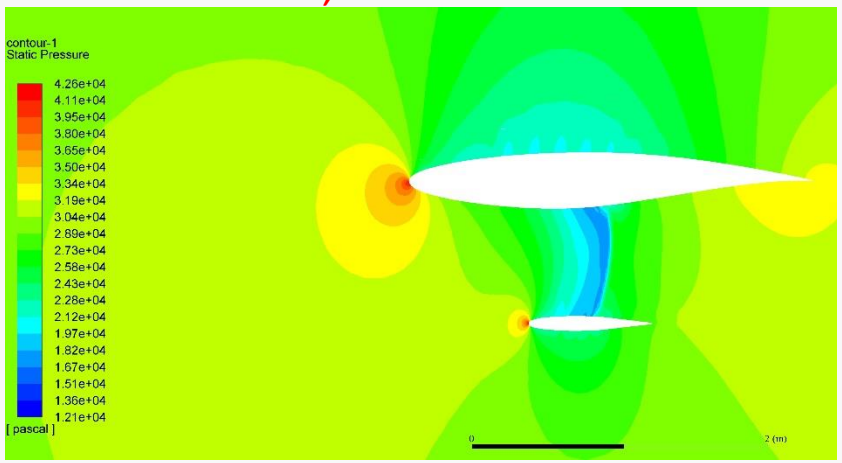


Y slice =14.5m

Little / No difference for KC; detached flow SCB

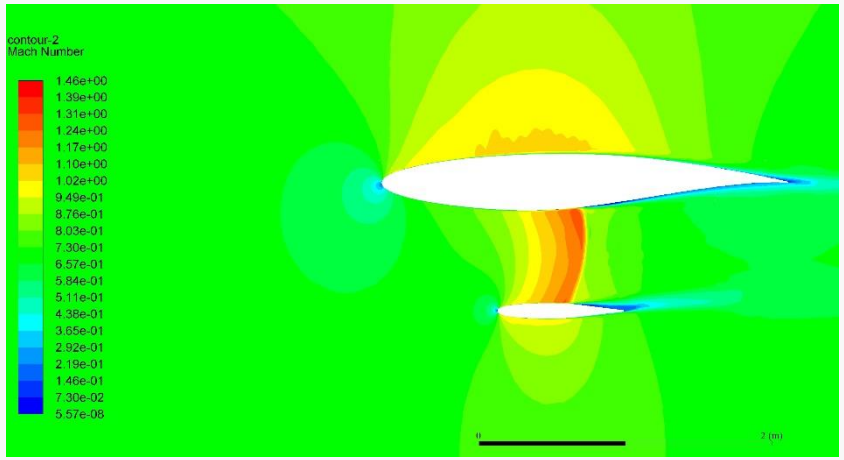




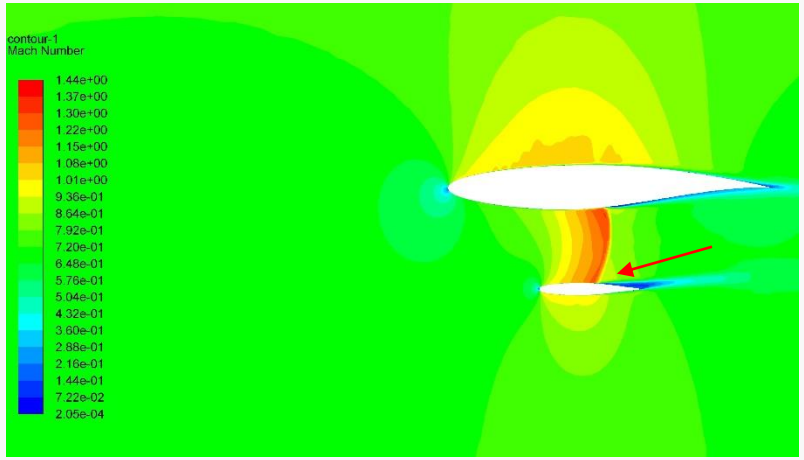


Results

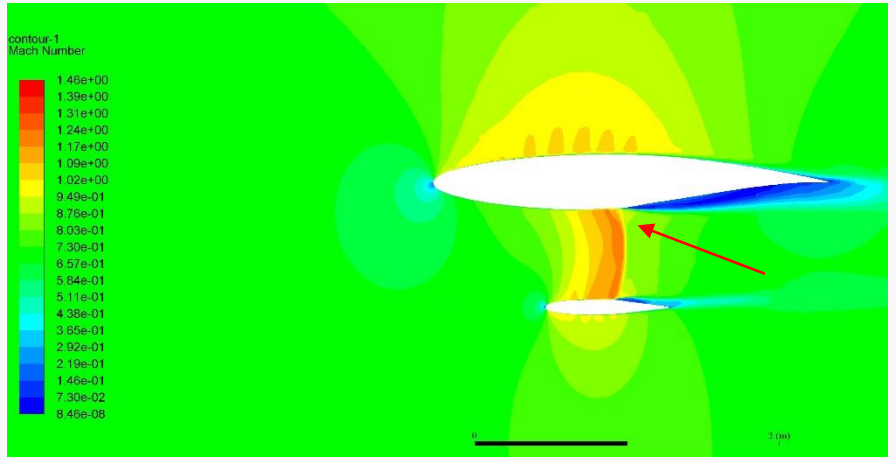
Baseline



Kuchemann Carrot

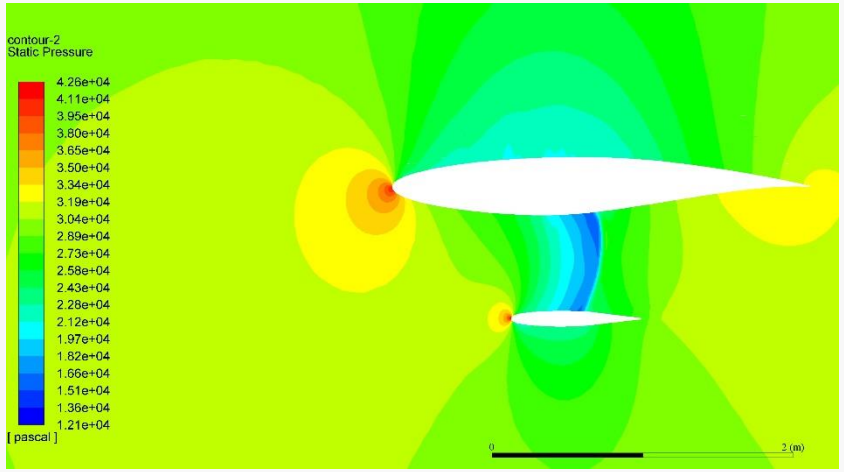


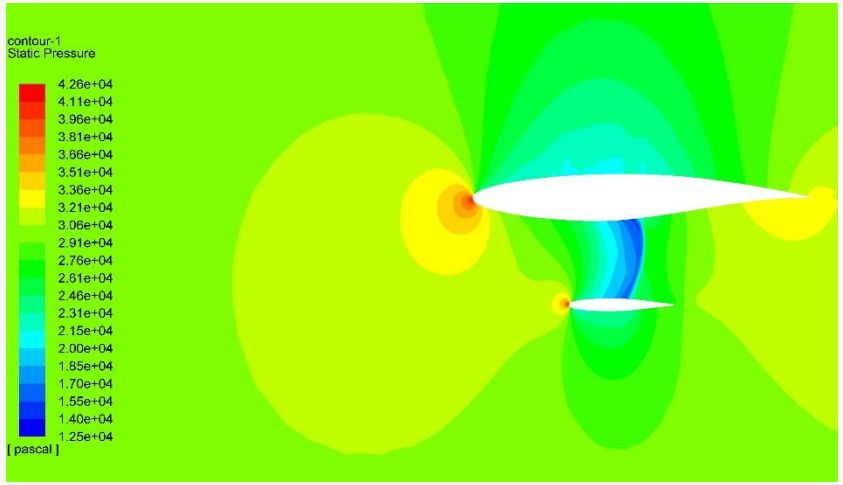
Shock Control Bump

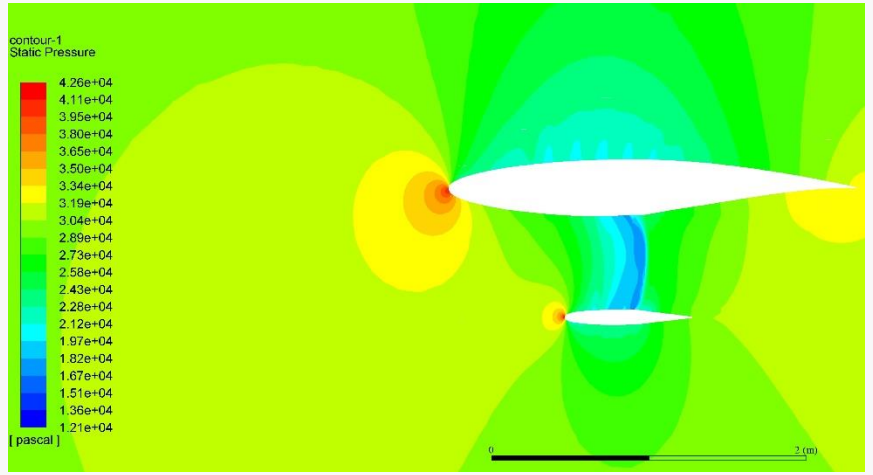


Y slice =15m

detached flow SCB and less on KC

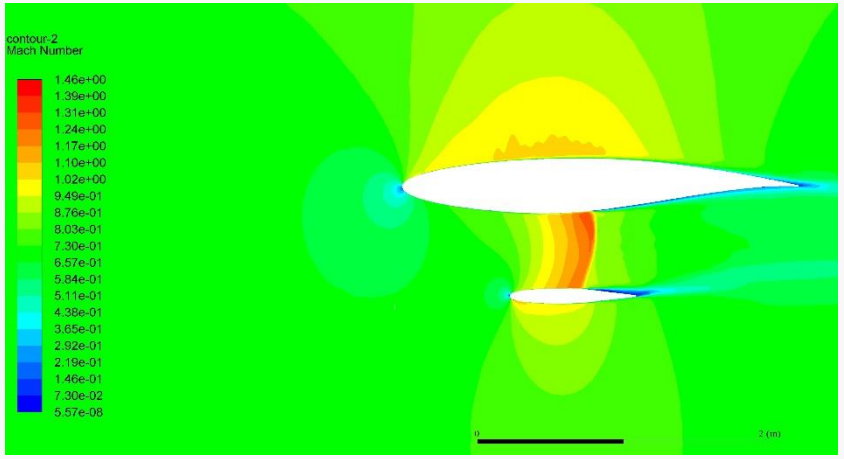




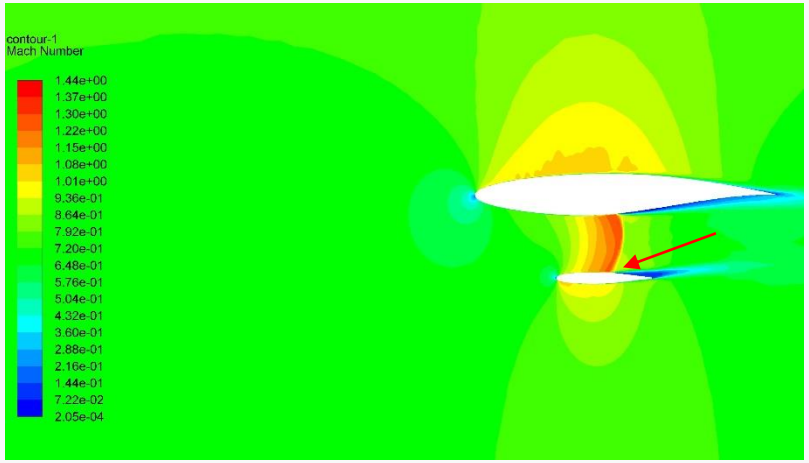


Results

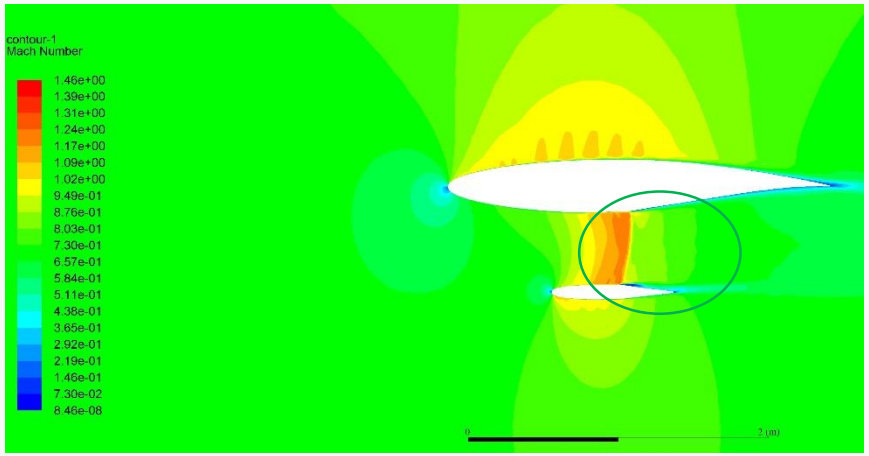
Baseline



Kuchemann Carrot

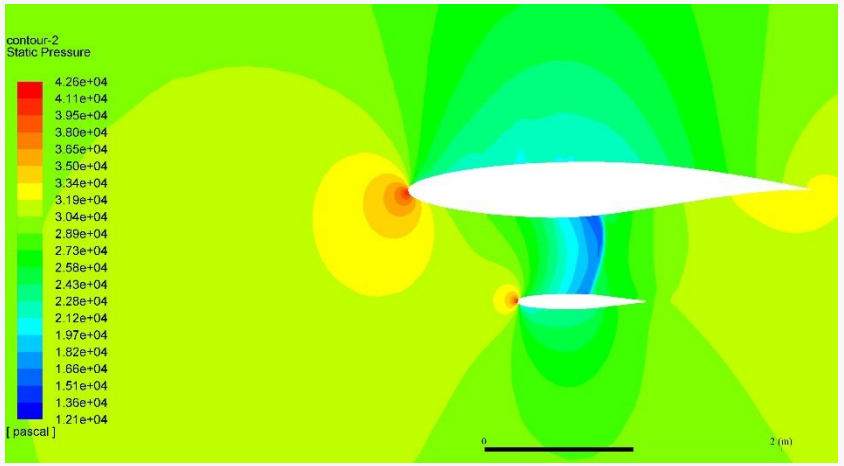


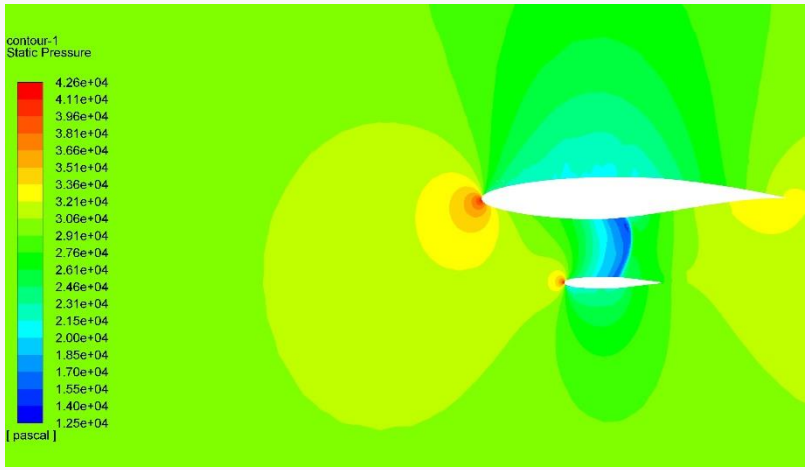
Shock Control Bump

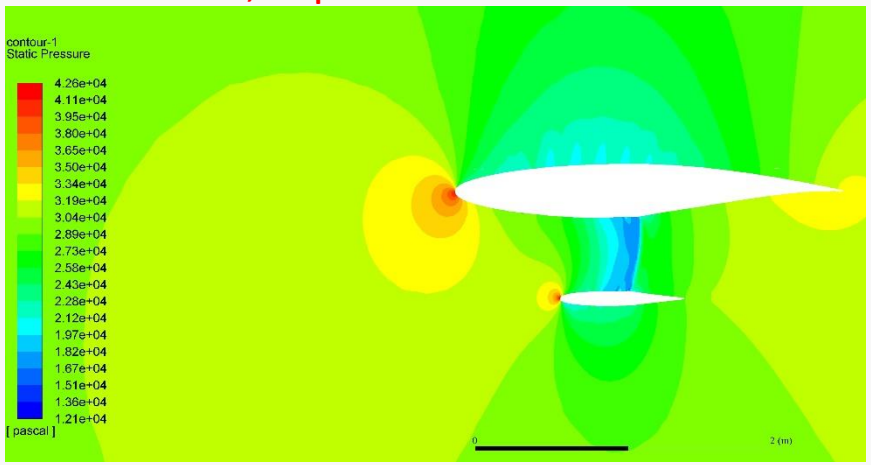


Y slice =15.5m

No detached flow SCB; separation for KC

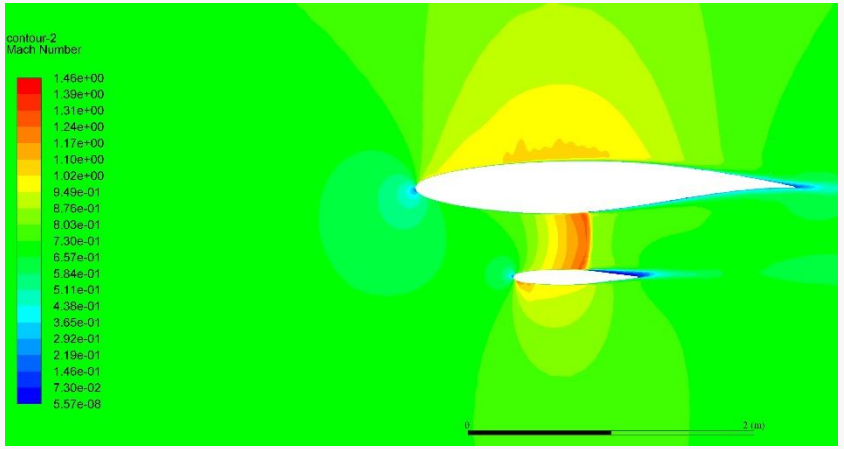




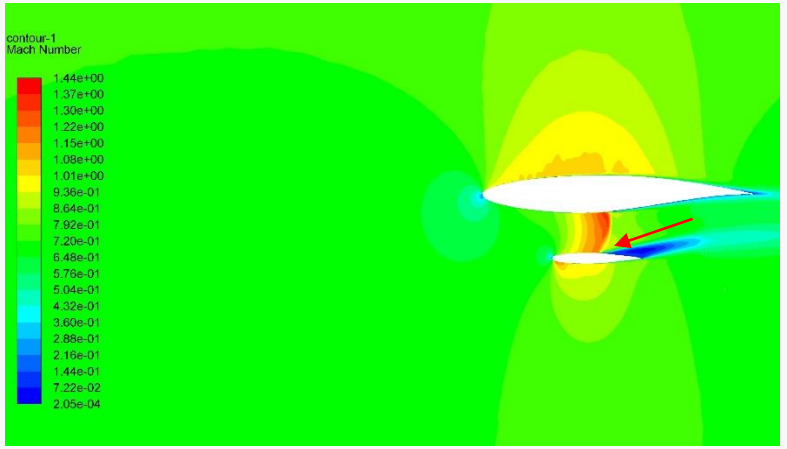


Results

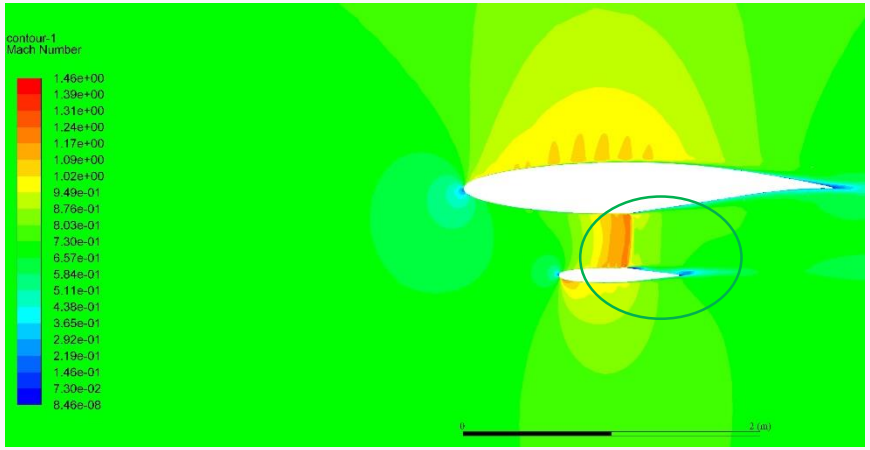
Baseline



Kuchemann Carrot

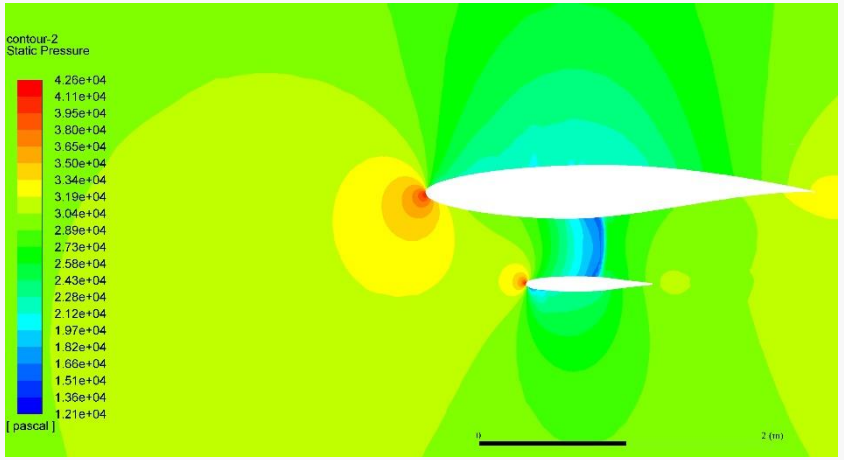


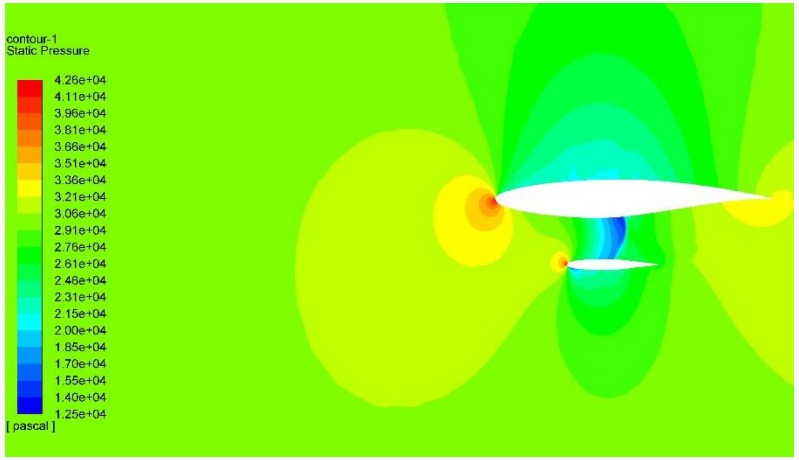
Shock Control Bump

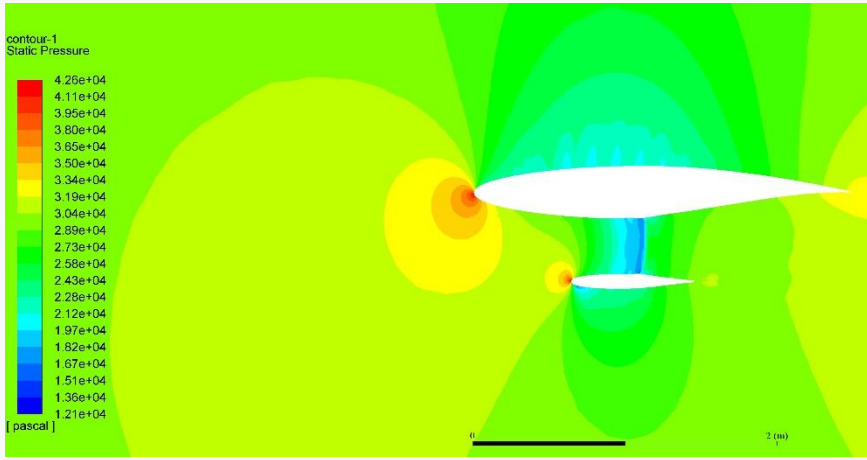


Y slice =16m

No detached flow SCB; separation for KC

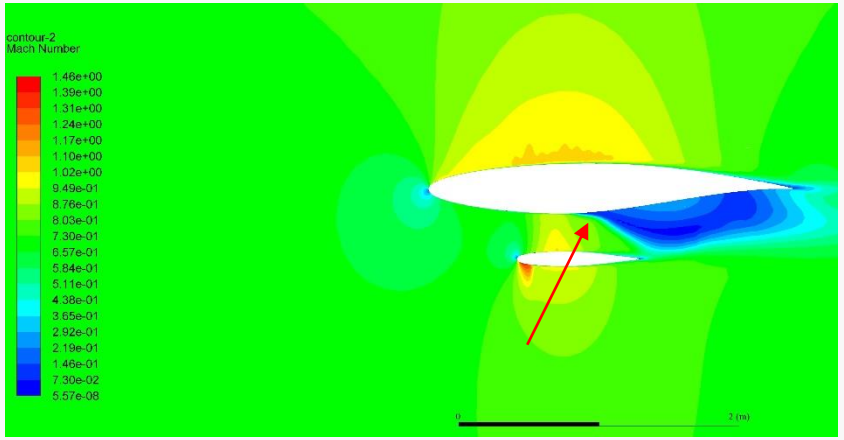




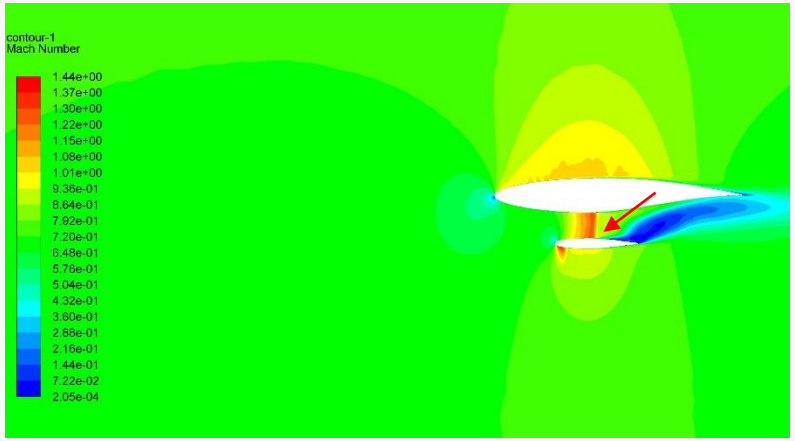


Results

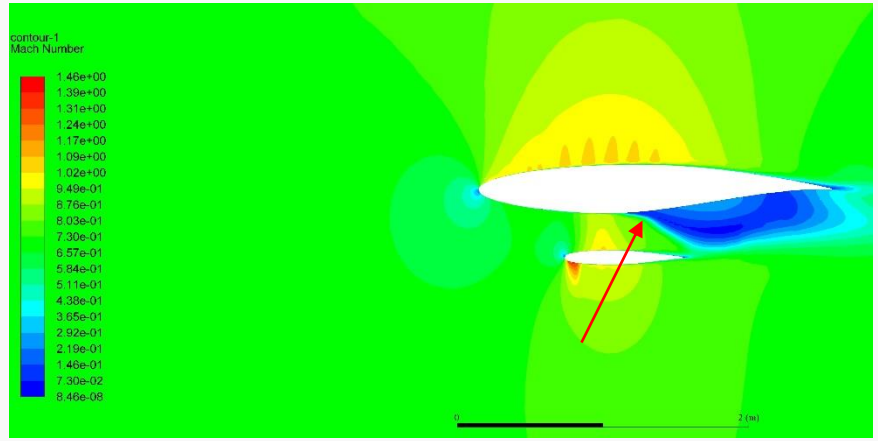
Baseline



Kuchemann Carrot

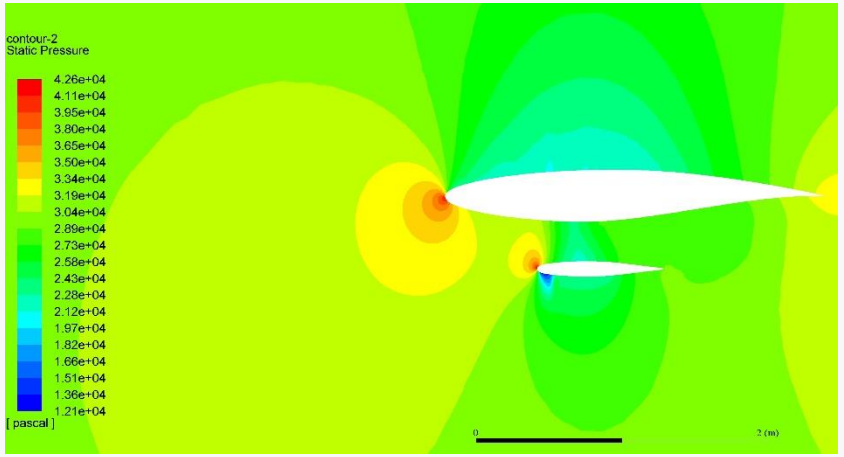


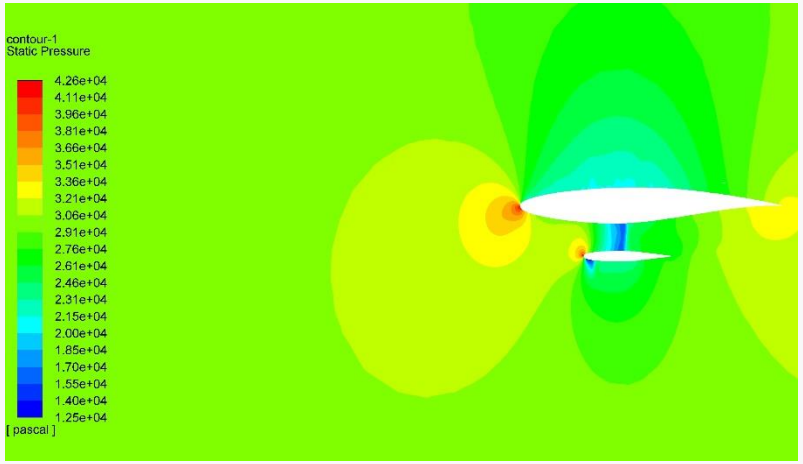
Shock Control Bump

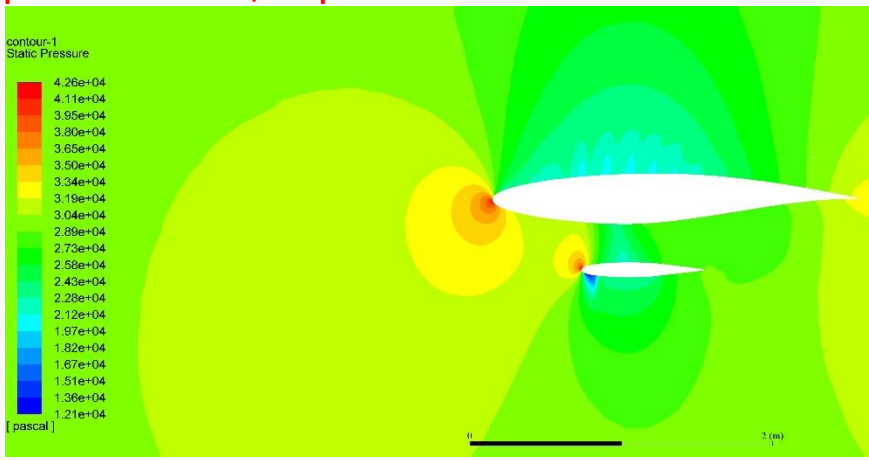


Y slice =16.5m

Massive separation SCB; separation for KC but smaller

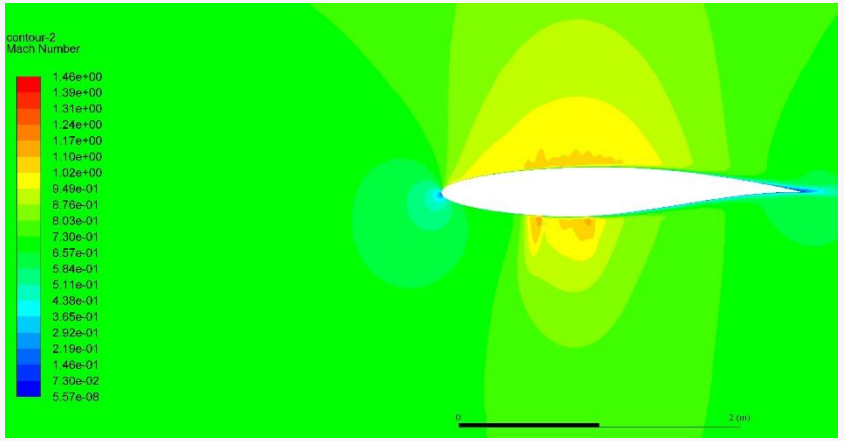




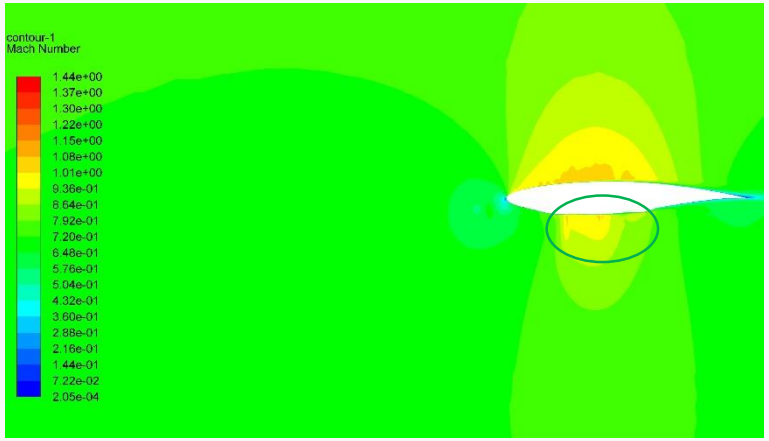


Results

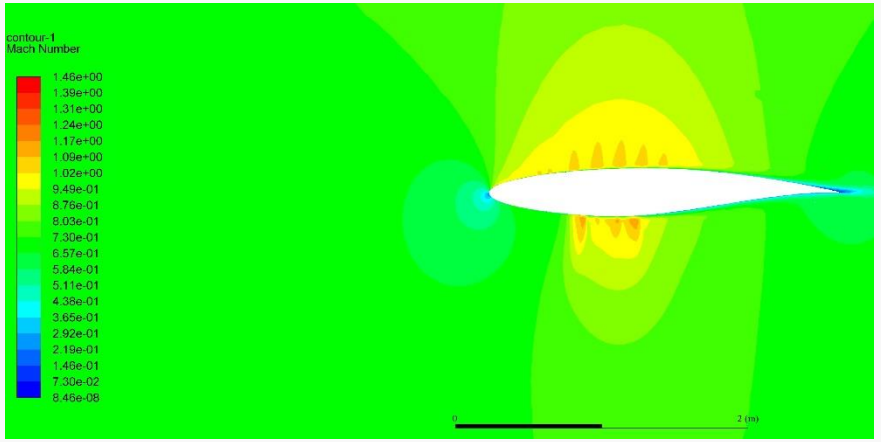
Baseline



Kuchemann Carrot

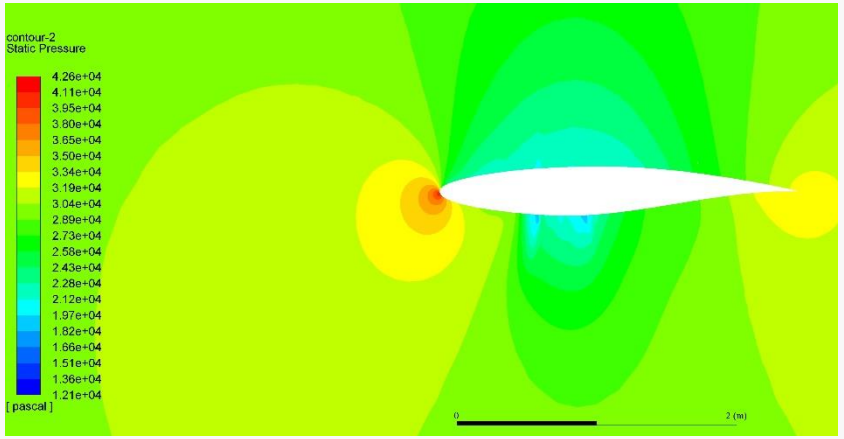


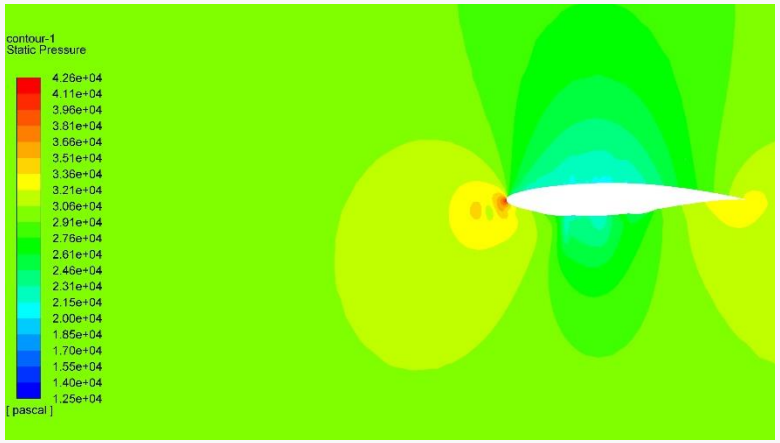
Shock Control Bump

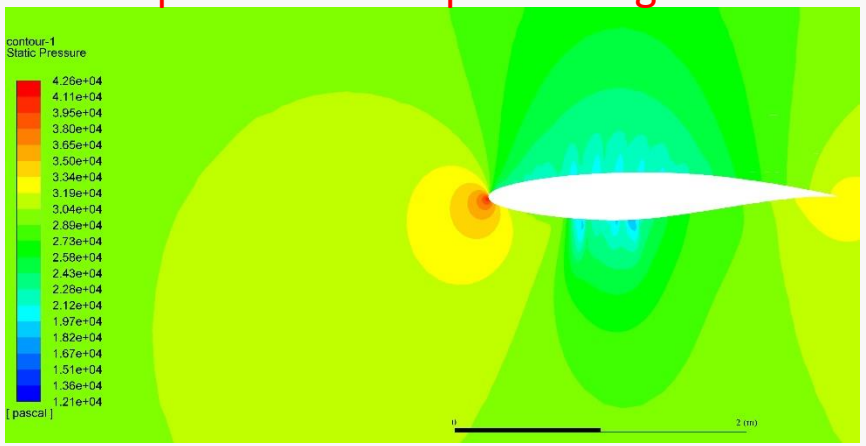


Y slice =16.8m

Less increased speed on outer panel wing KC

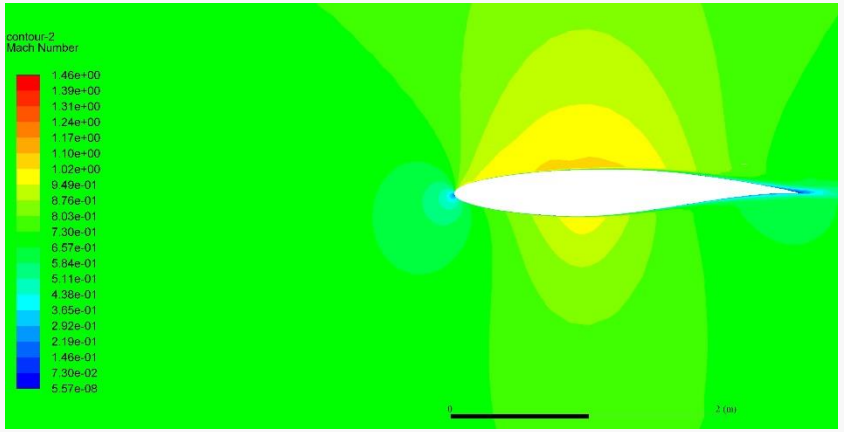




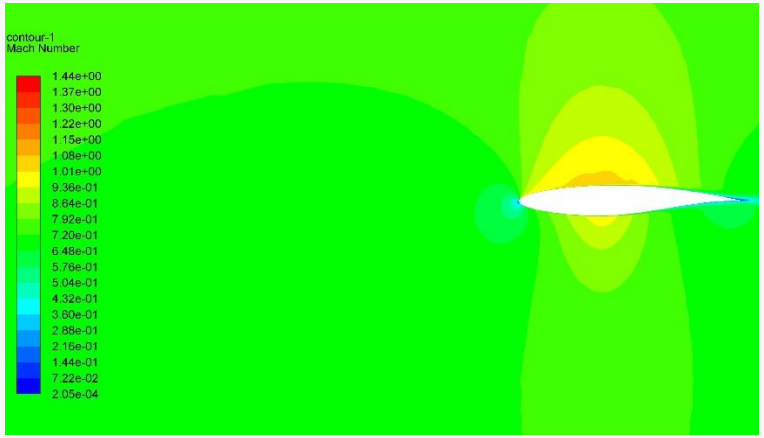


Results

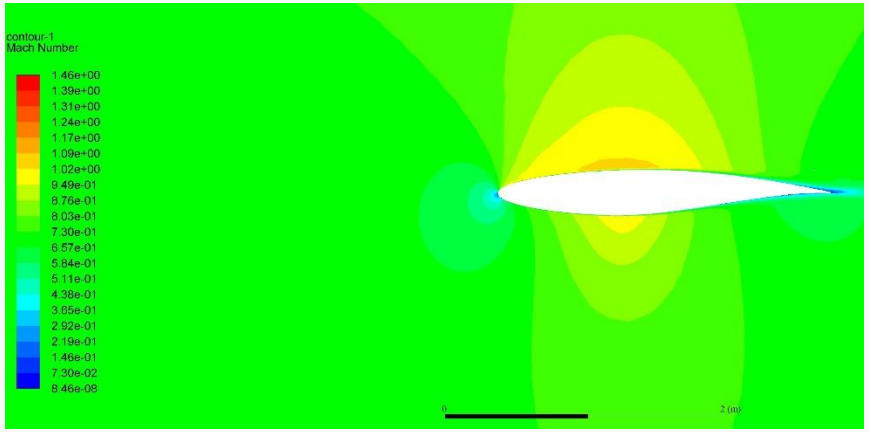
Baseline



Kuchemann Carrot

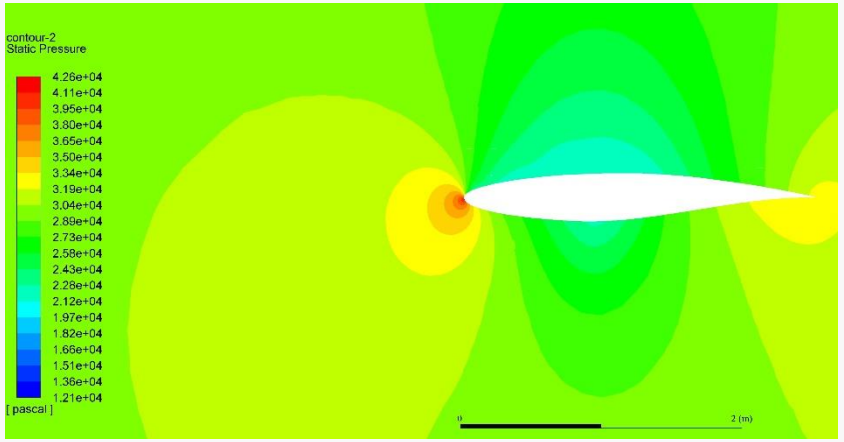


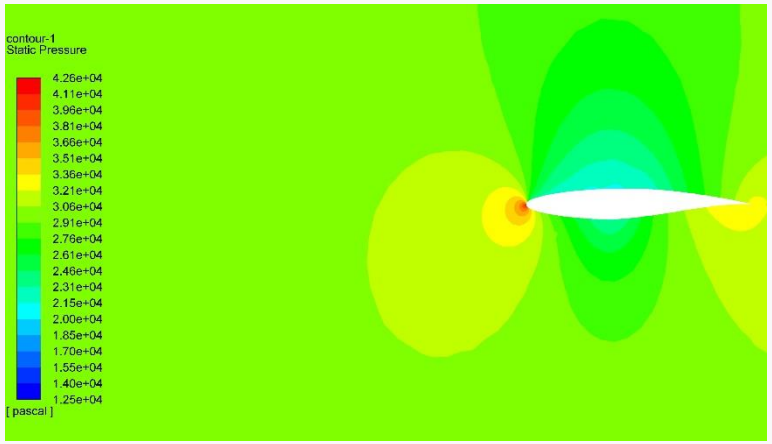
Shock Control Bump

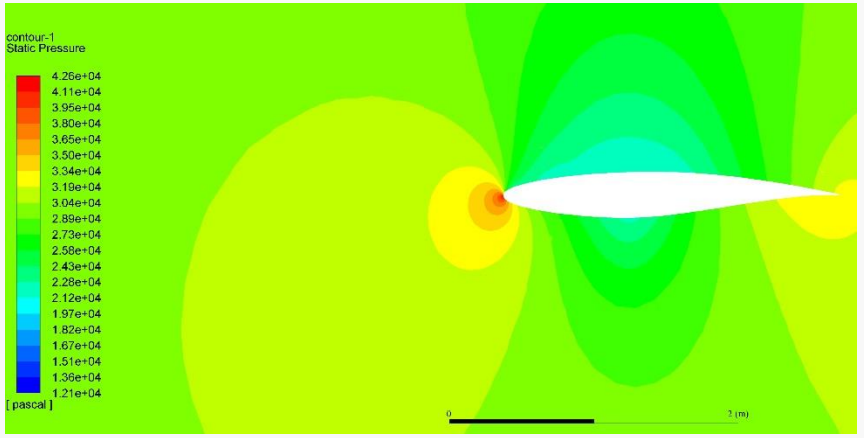


Y slice =17.3m

Little / No difference

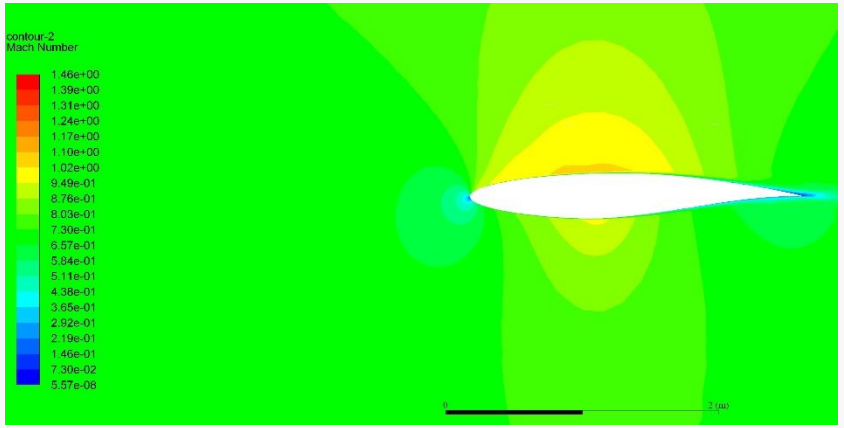




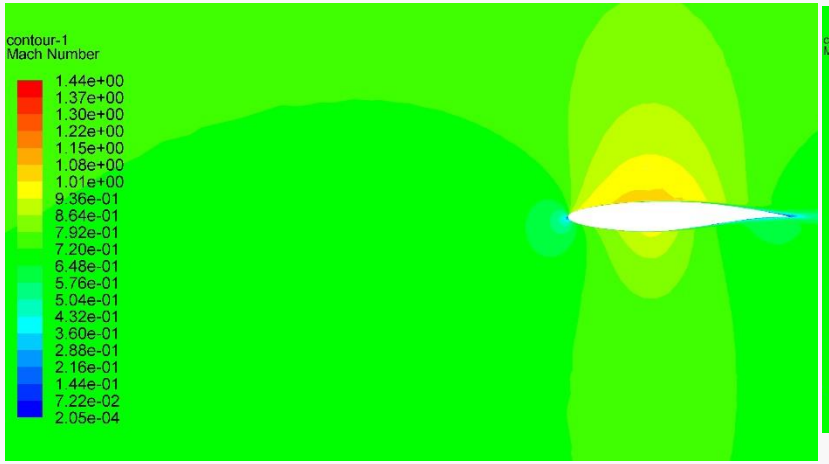


Results

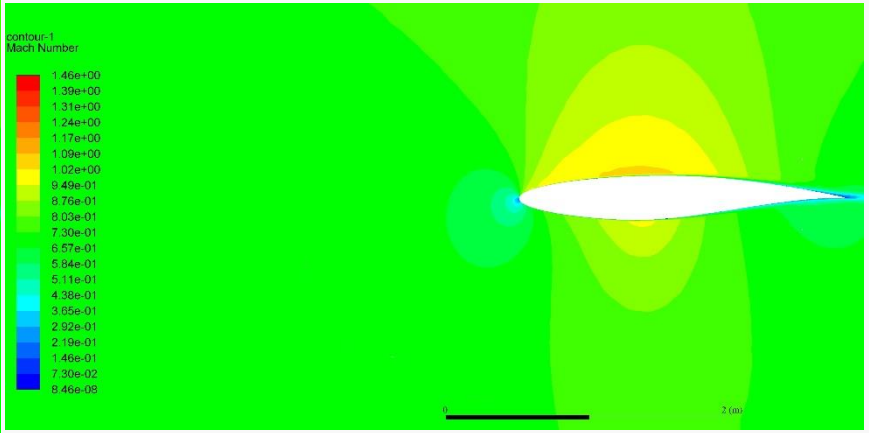
Baseline



Kuchemann Carrot

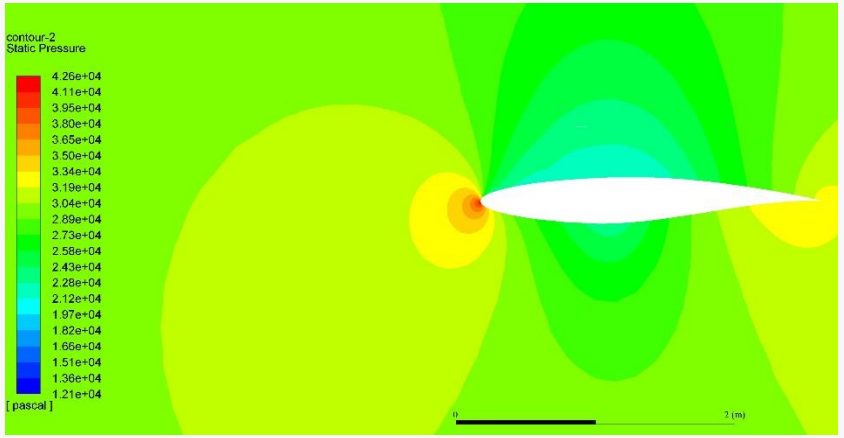


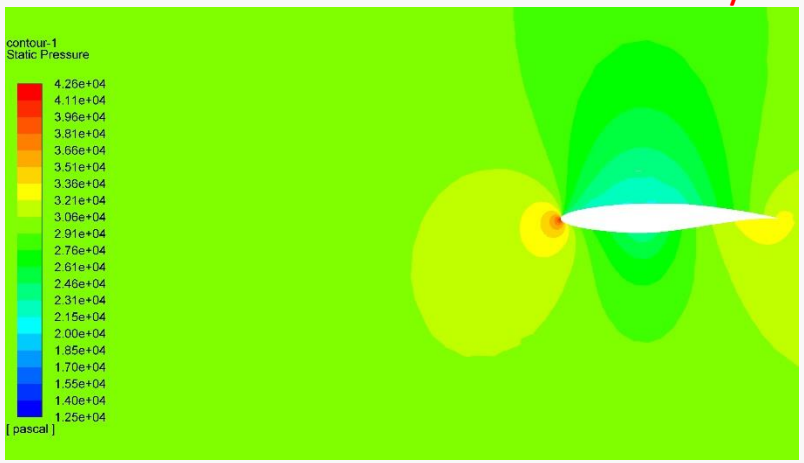
Shock Control Bump

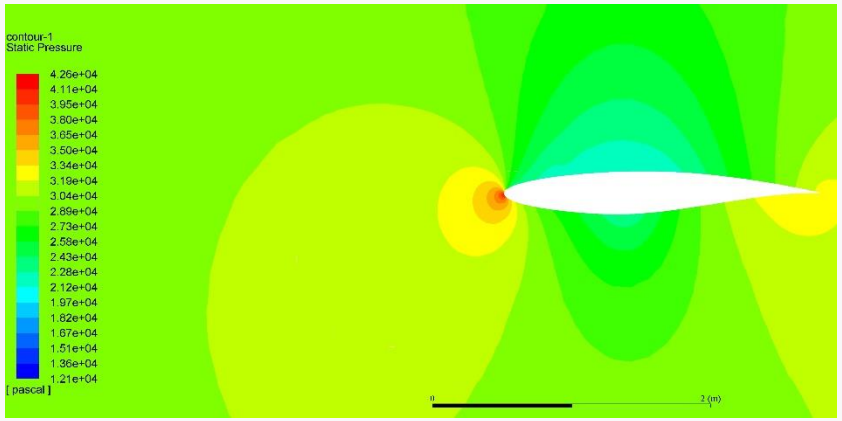


Y slice =17.8m

Little / No difference

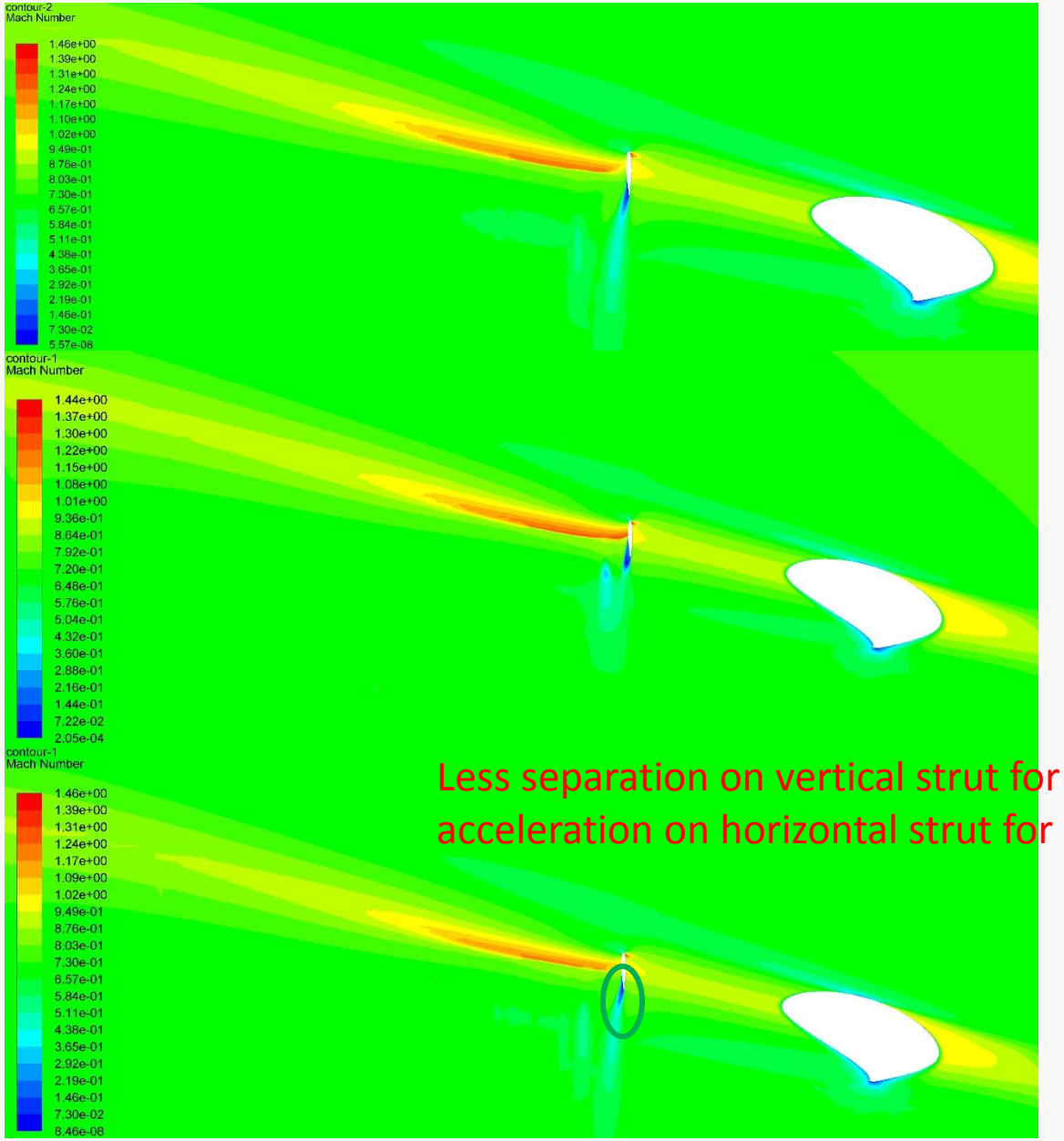






Results

Z slice =0.87m

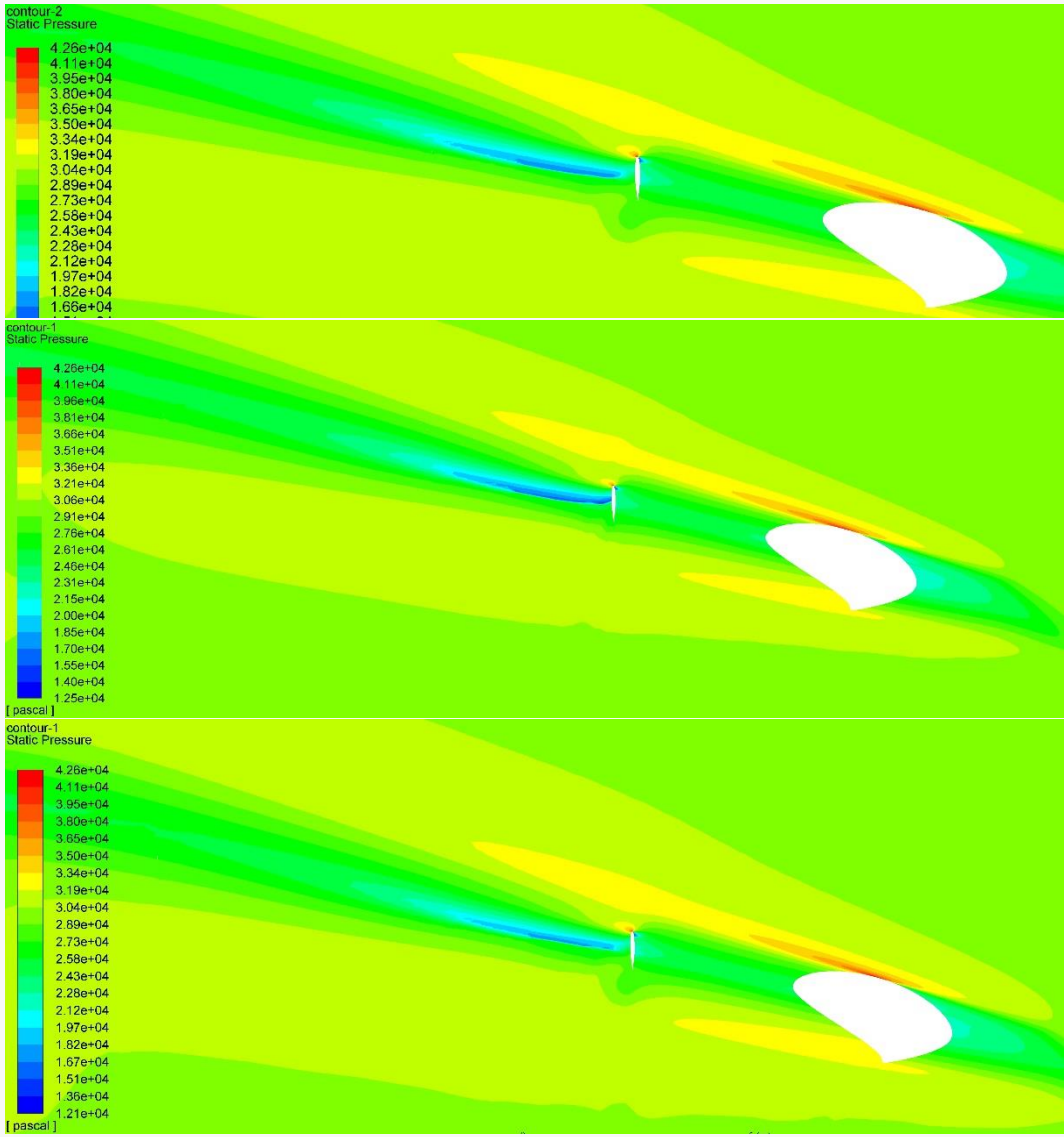


Baseline

Kuchemann Carrot

Shock Control Bump

Less separation on vertical strut for SCB and less acceleration on horizontal strut for SCB



Results

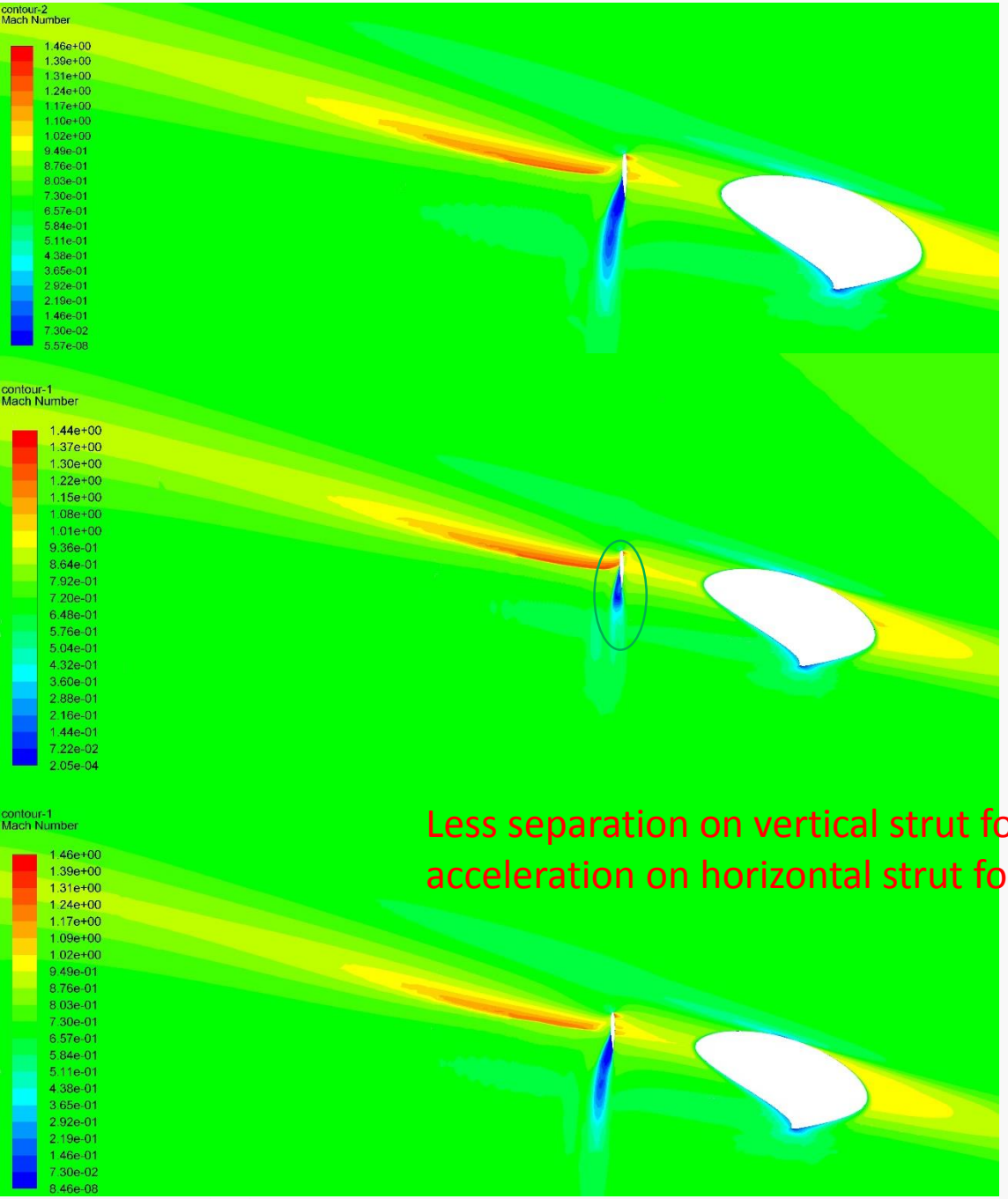
Z slice =0.97m

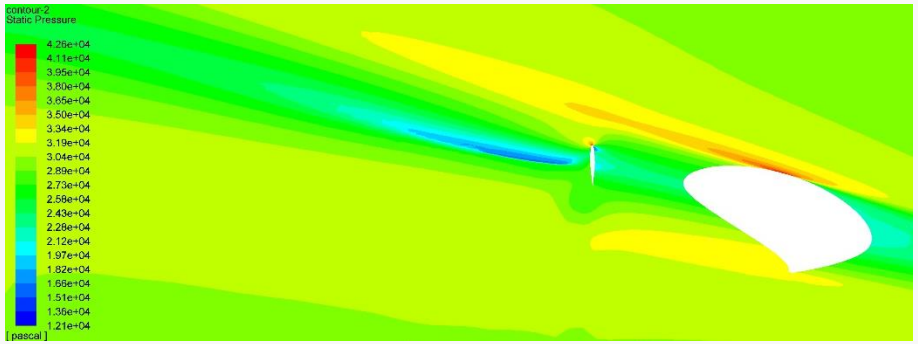
Baseline

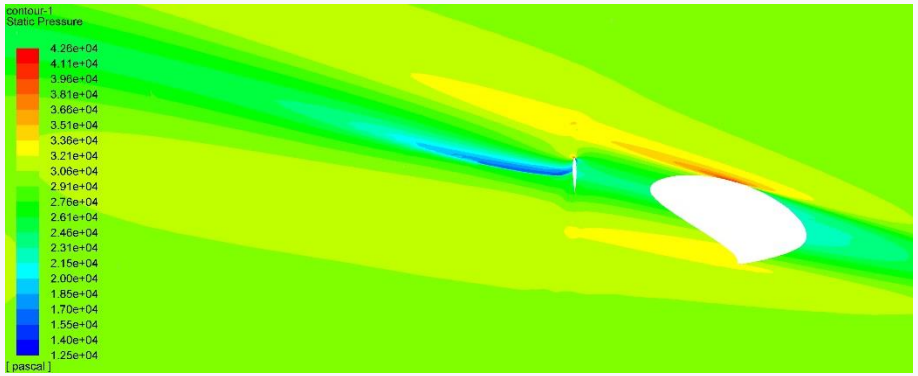
Kuchemann Carrot

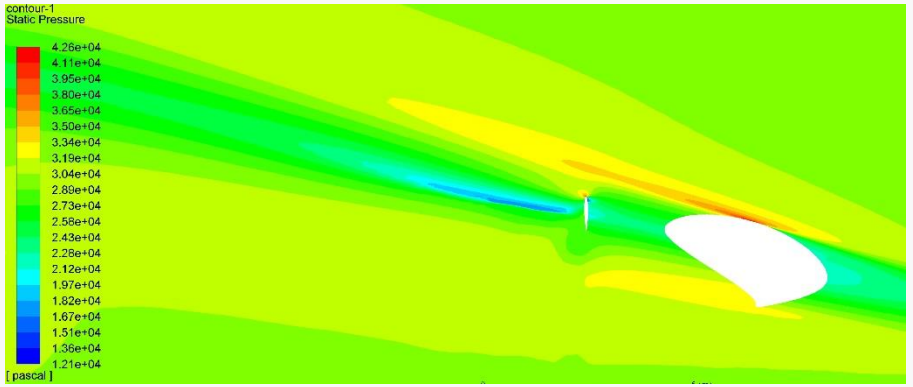
Shock Control Bump

Less separation on vertical strut for KC and less acceleration on horizontal strut for SCB



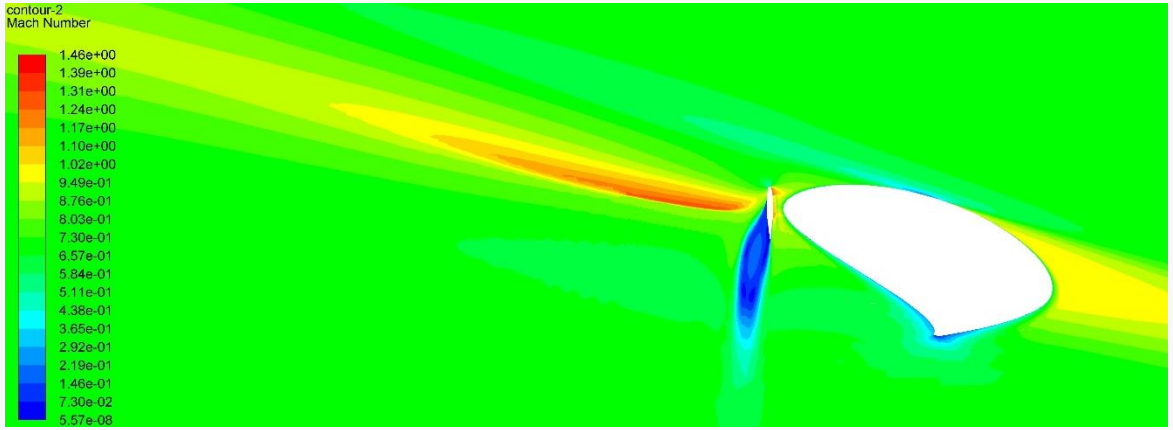




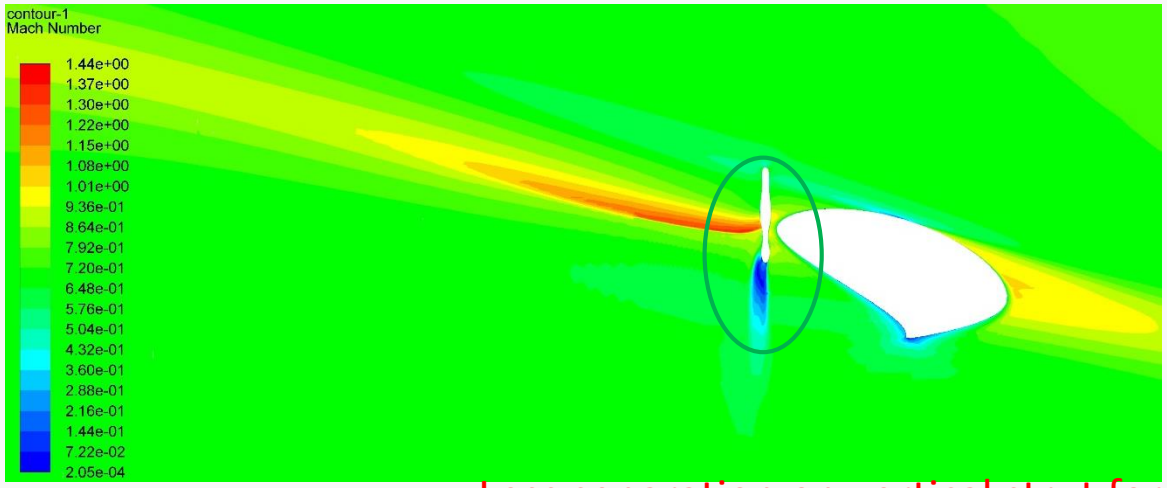


Results

Z slice =1.07m

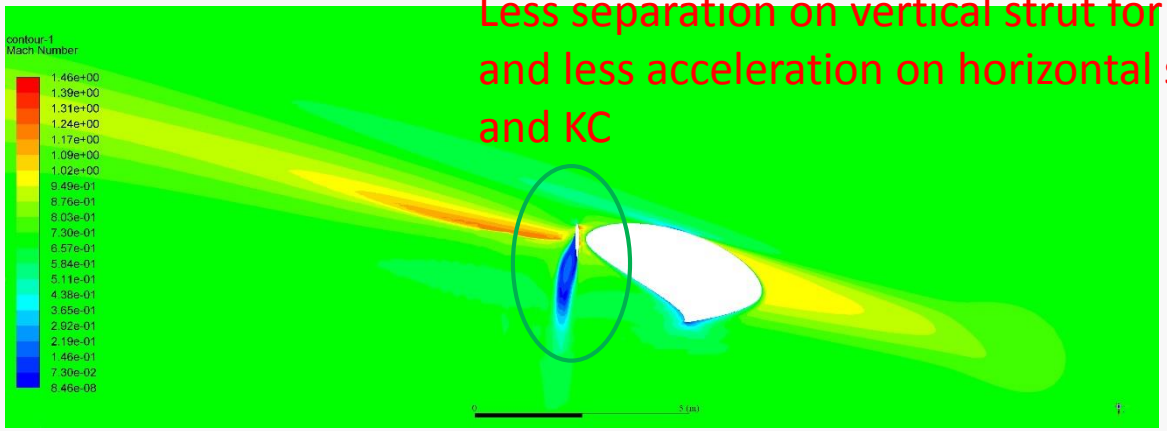


Baseline

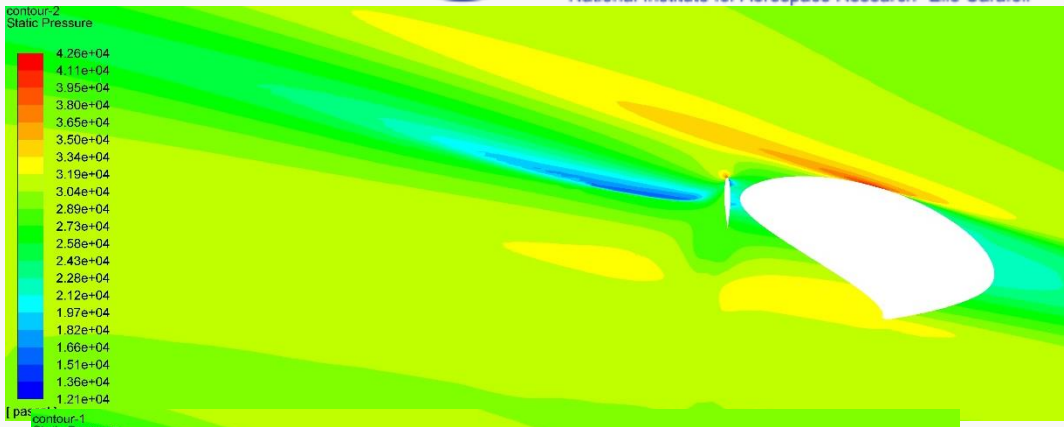


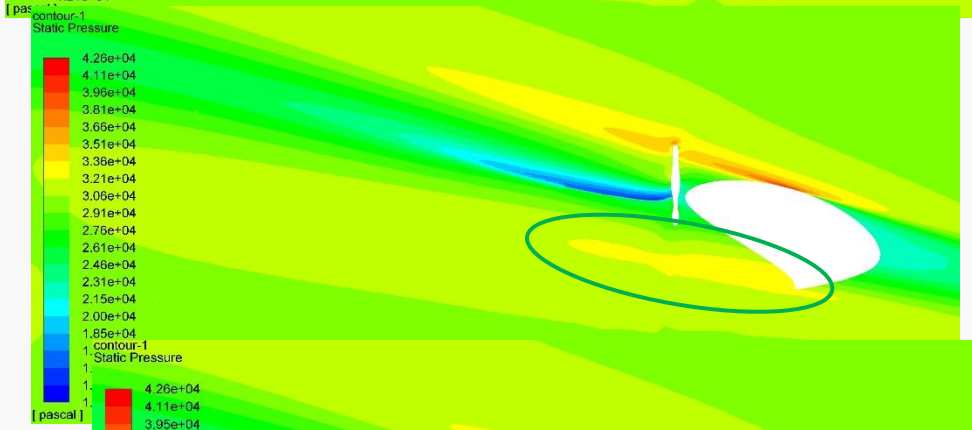
Kuchemann
Carrot

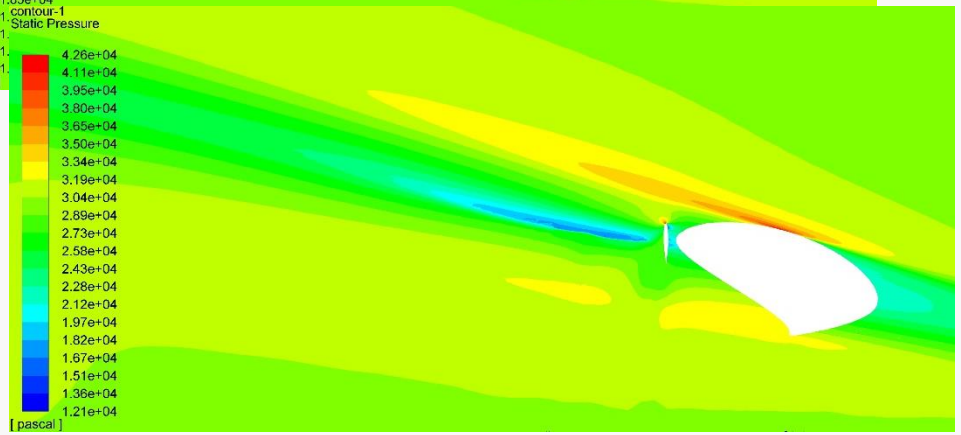
Less separation on vertical strut for KC and SCB and less acceleration on horizontal strut for SCB and KC

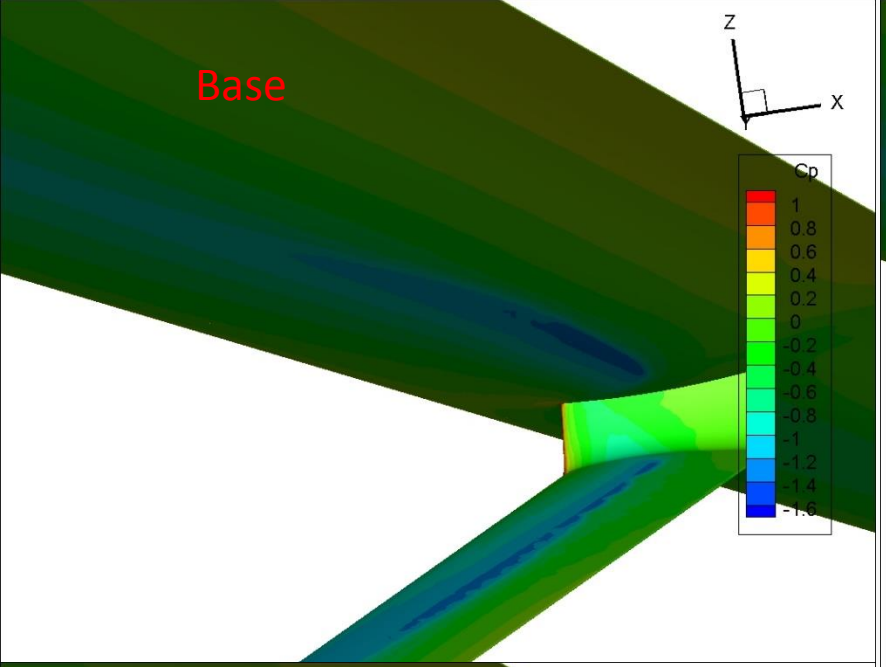


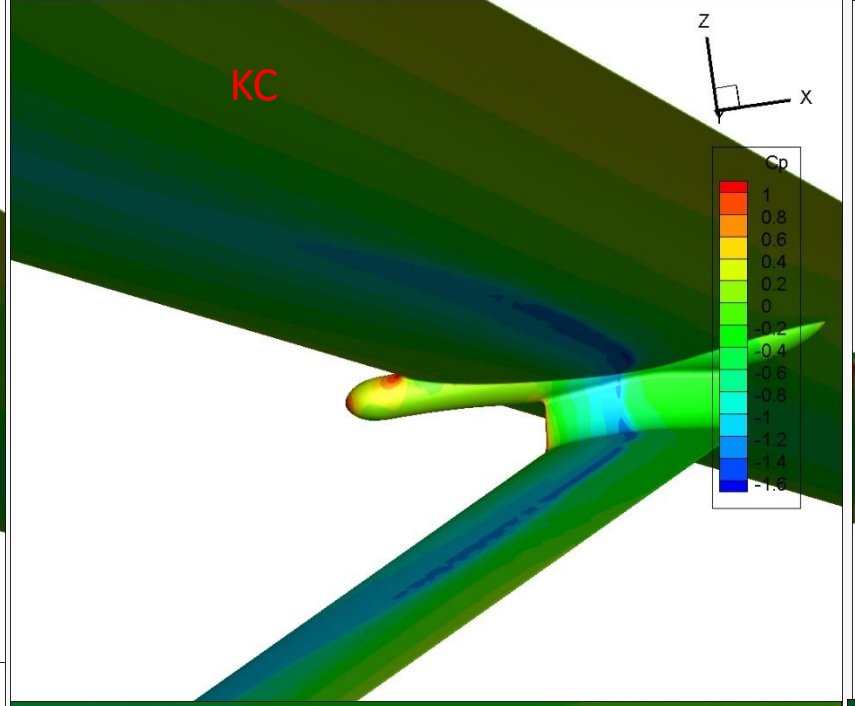
Shock Control
Bump

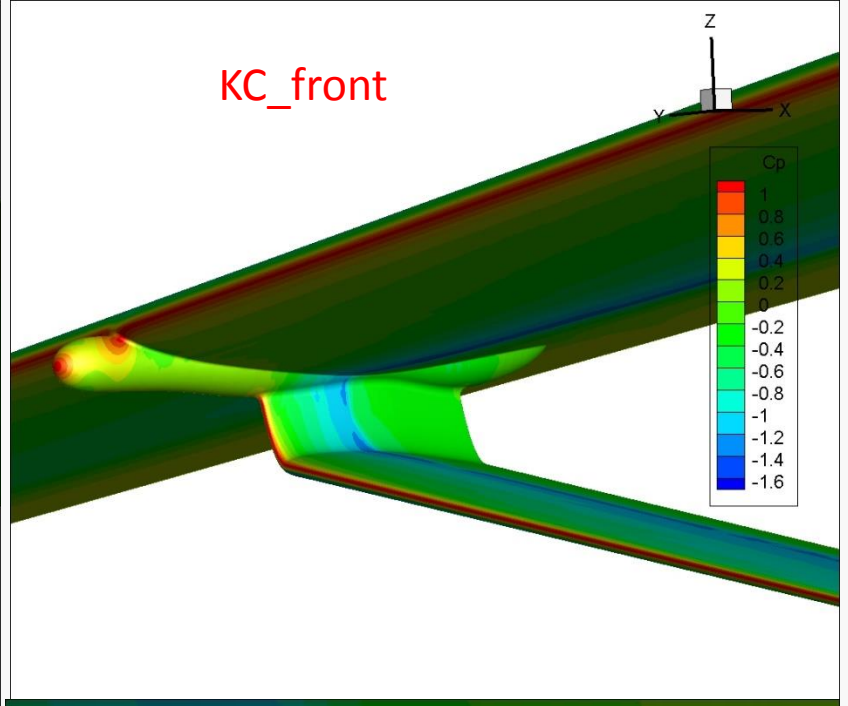


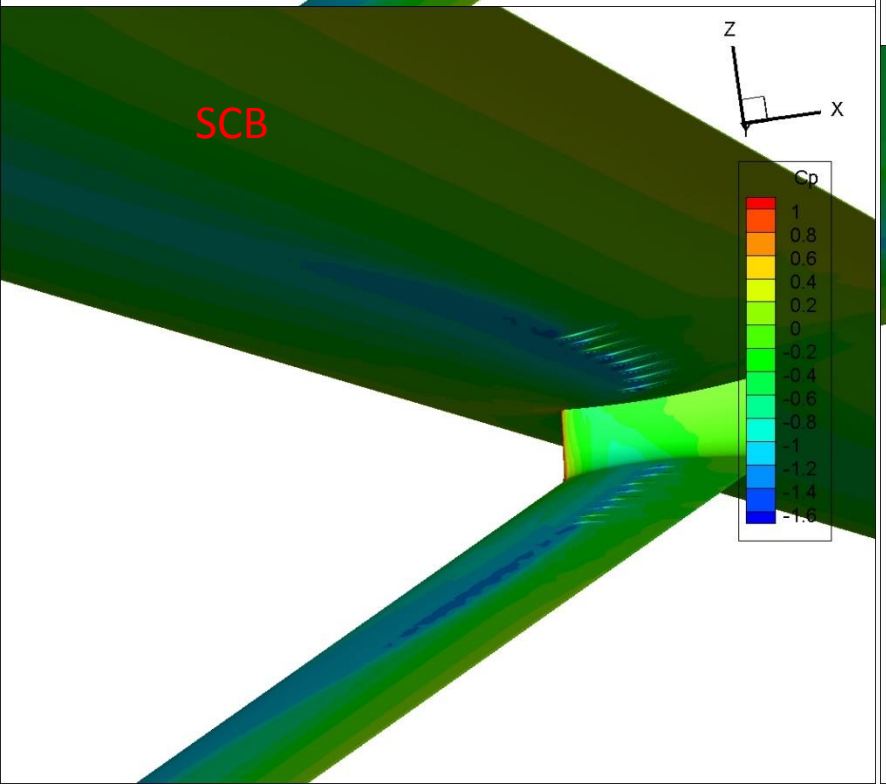


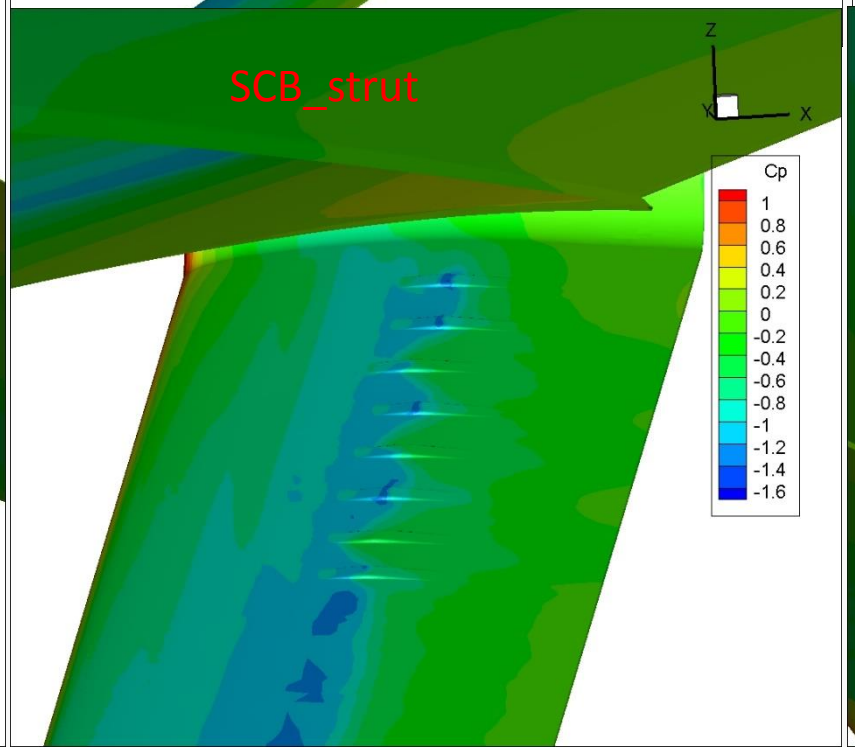


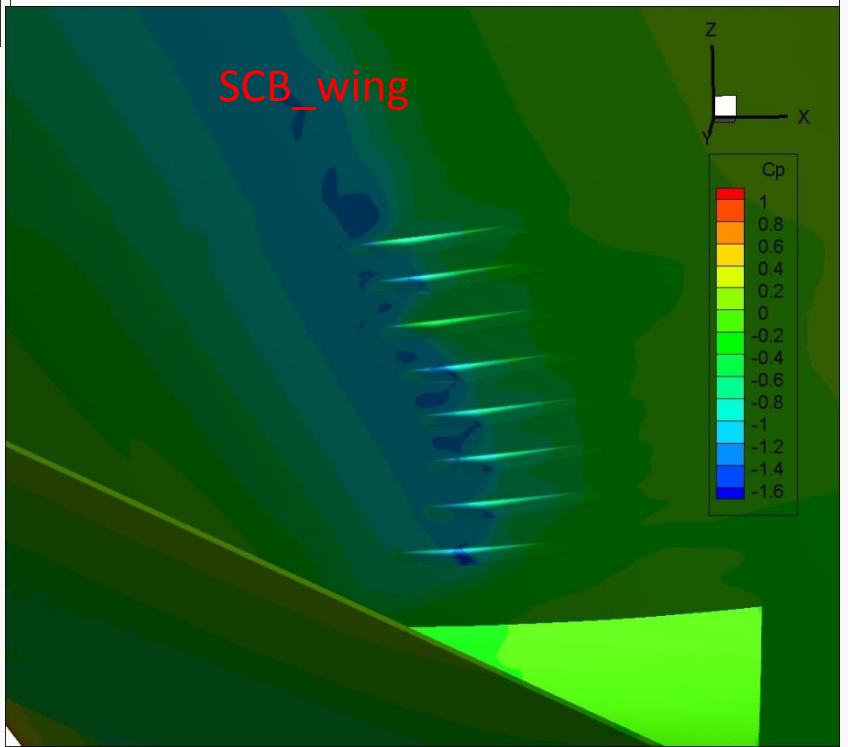

Base
Z
X
Cp
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4


KC
Z
X
Cp
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4


KC_front
Z
X
Cp
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6

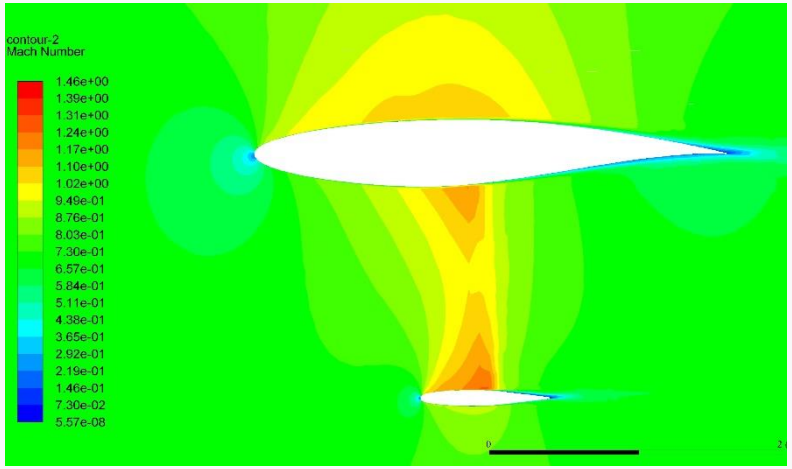

SCB
Z
X
Cp
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4


SCB_strut
Z
X
Cp
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6

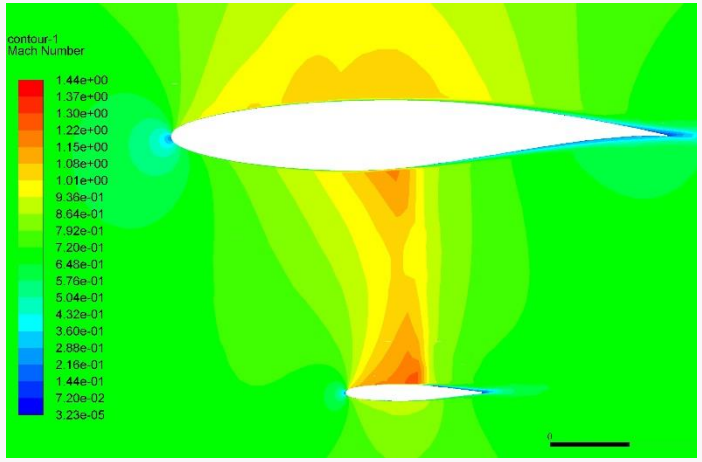

SCB_wing
Z
X
Cp
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6

Results

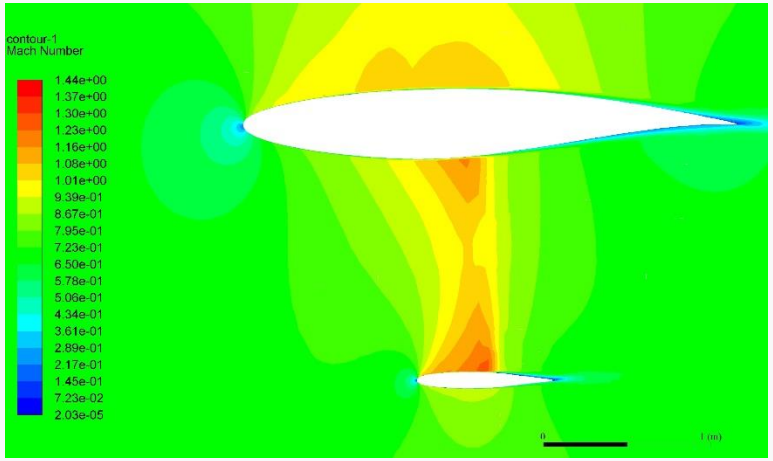
Baseline



KC-SCB_v0

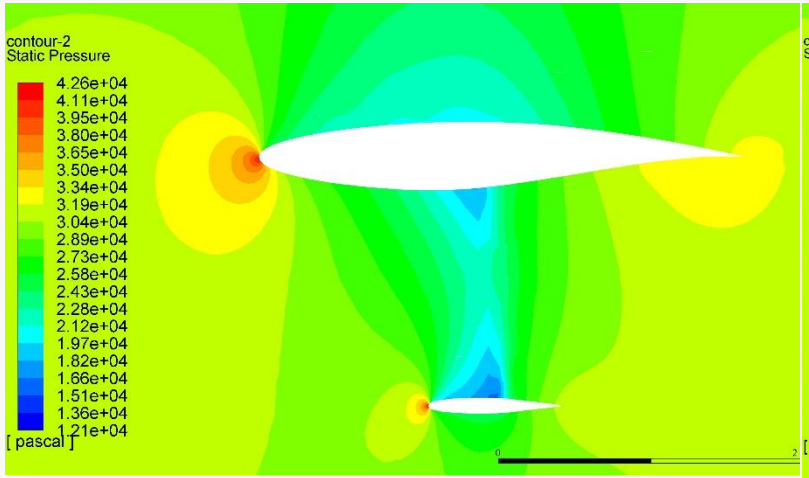


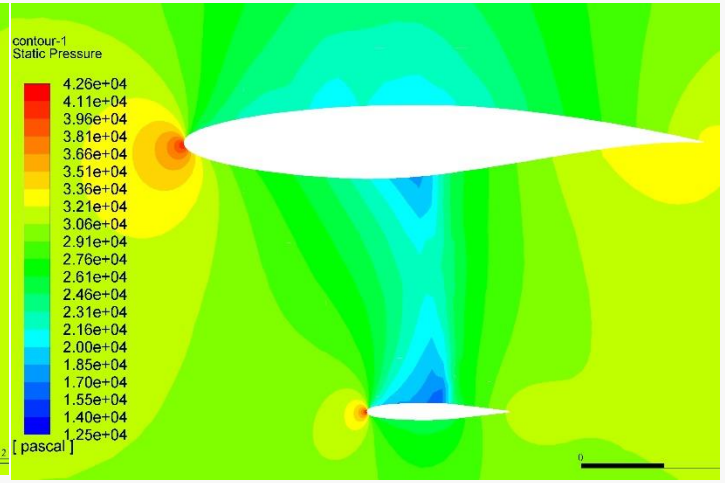
KC-SCB_v2

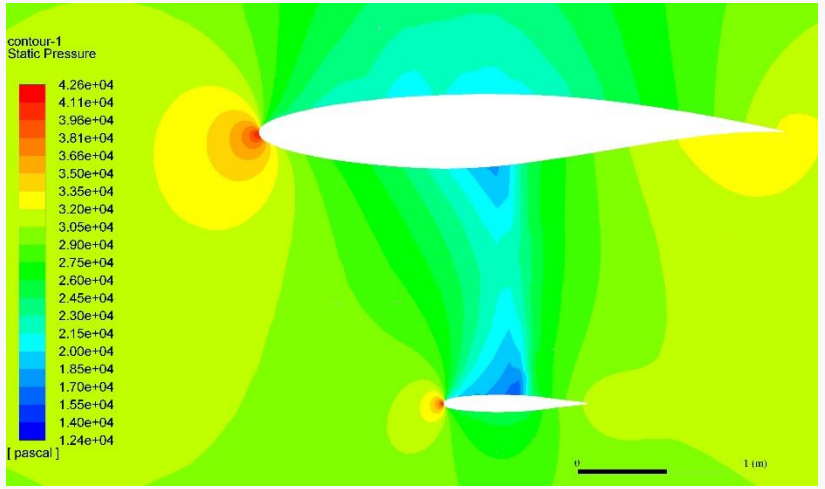


Y slice =12m

Little / No difference

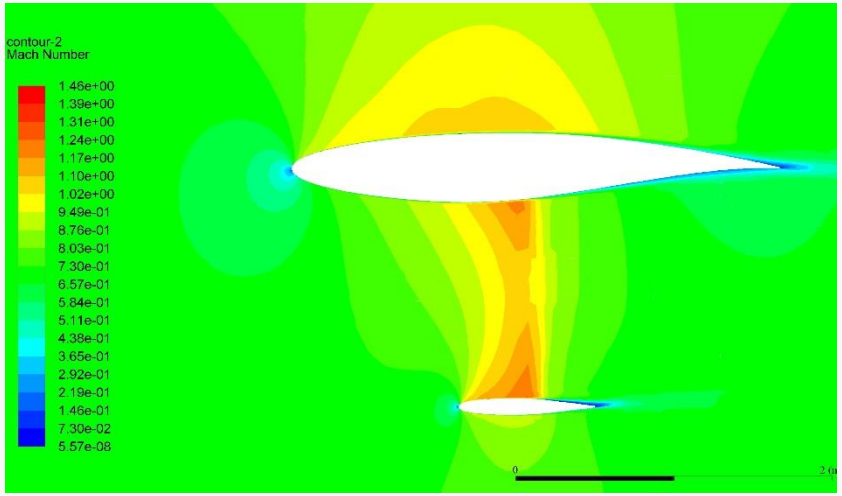




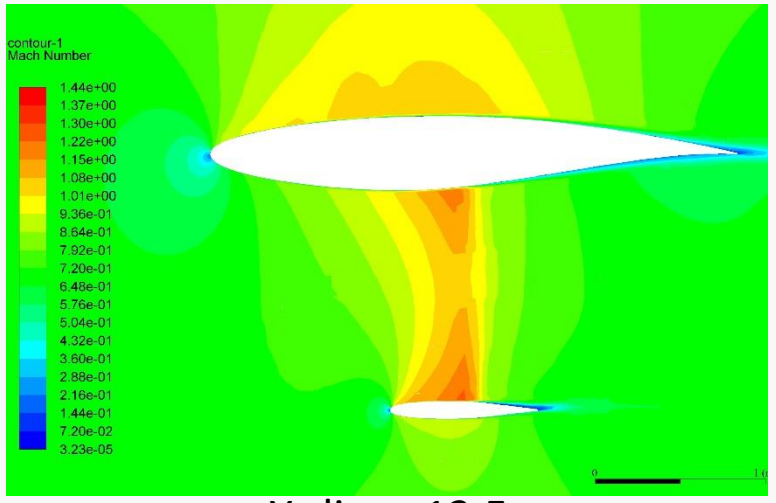


Results

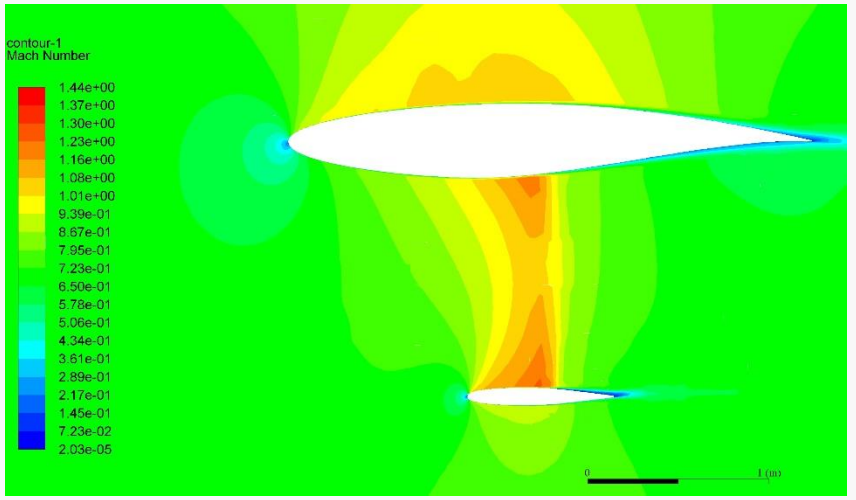
Baseline



KC-SCB_v0

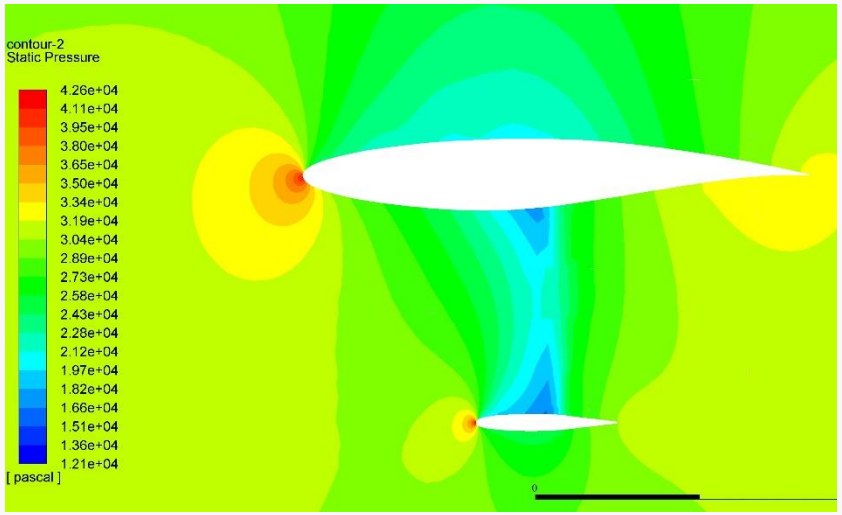


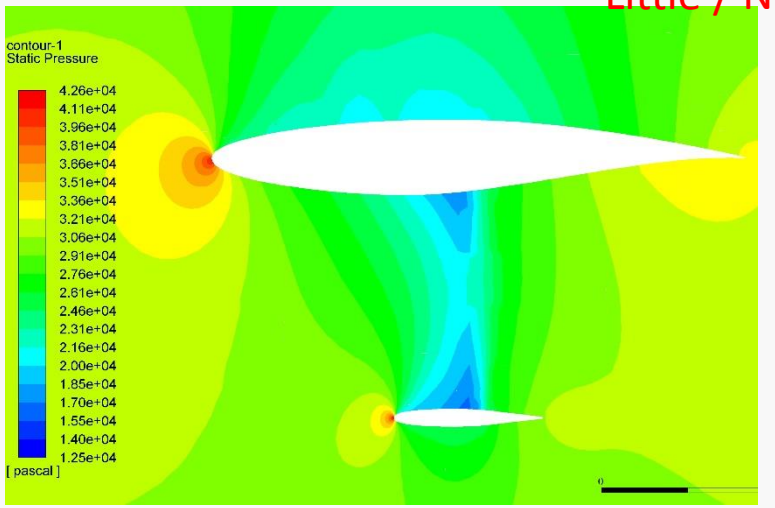
KC-SCB_v2

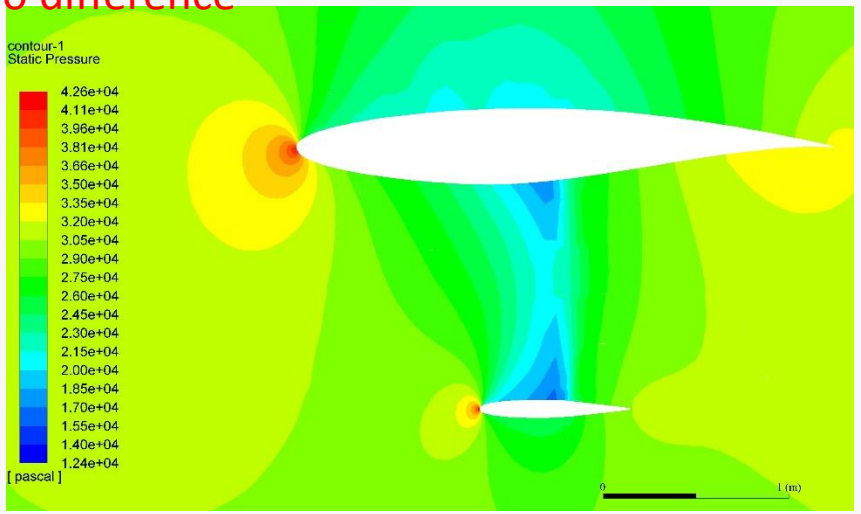


Y slice =12.5m

Little / No difference

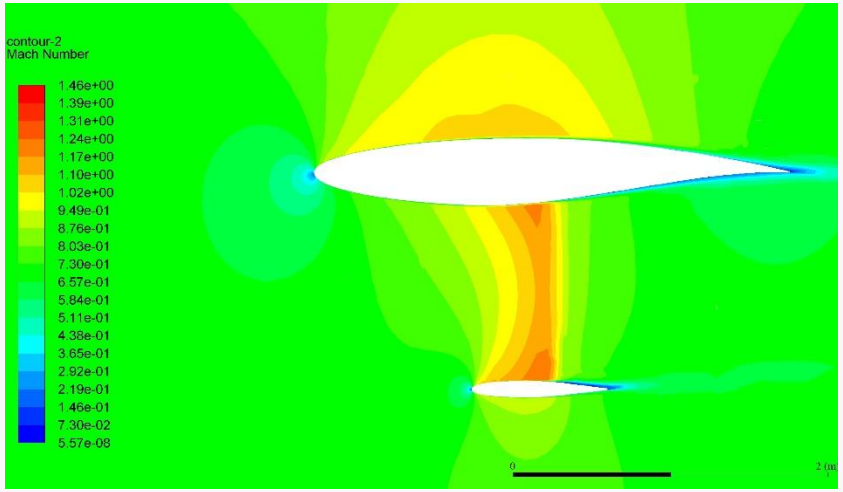




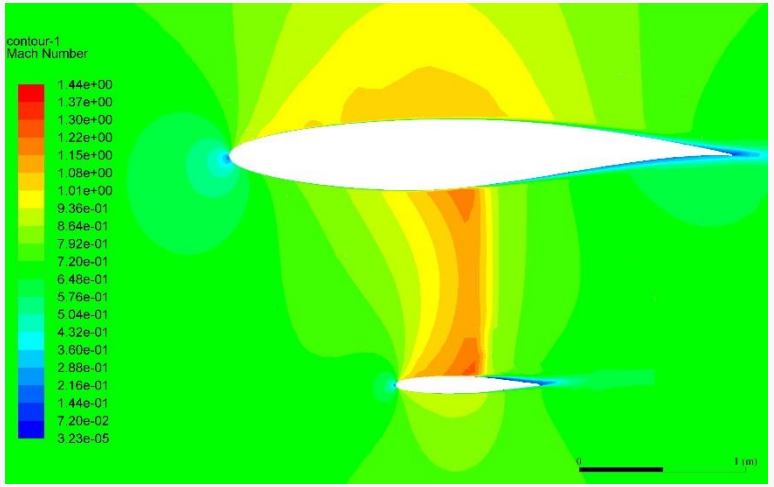


Results

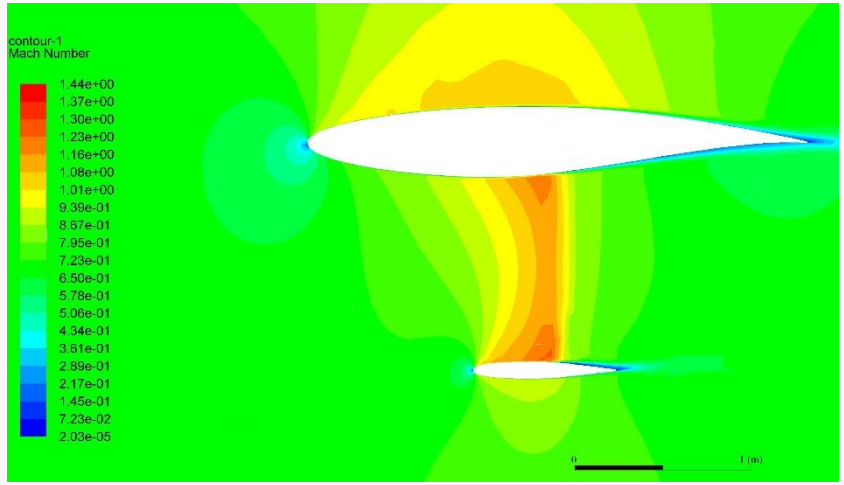
Baseline



KC-SCB_v0

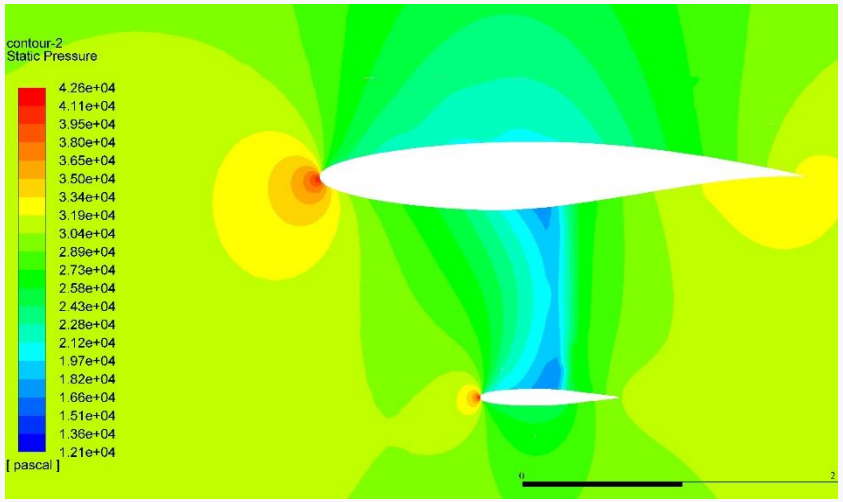


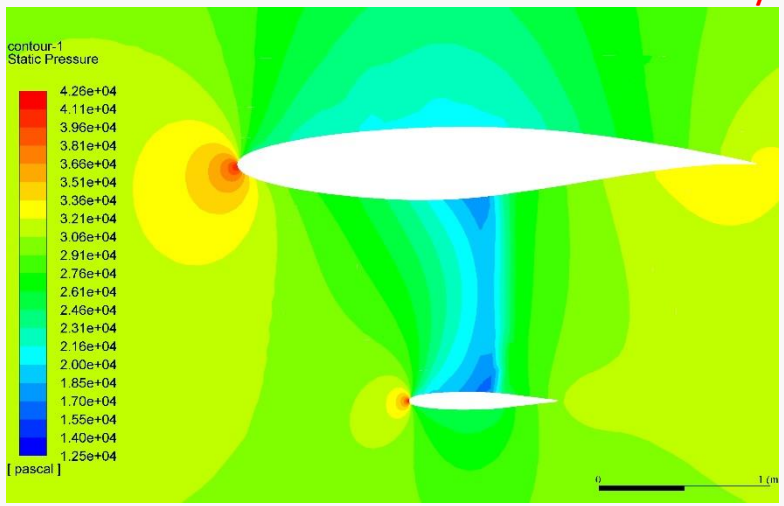
KC-SCB_v2

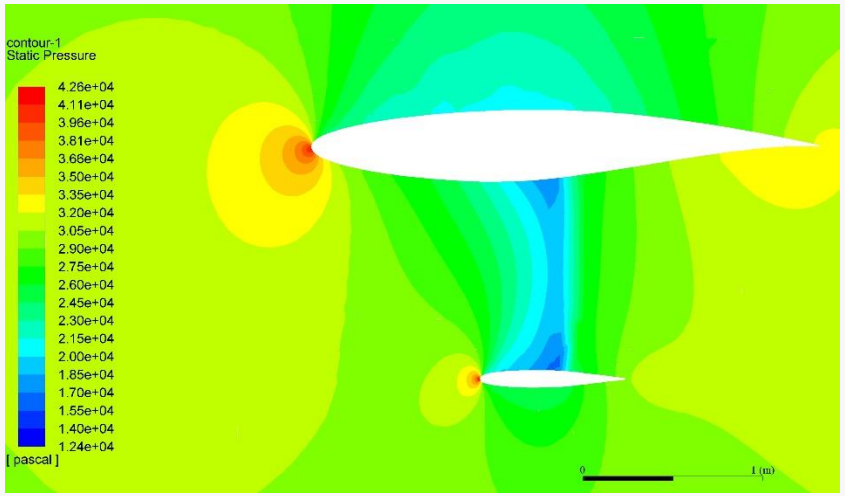


Y slice =13m

Little / No difference

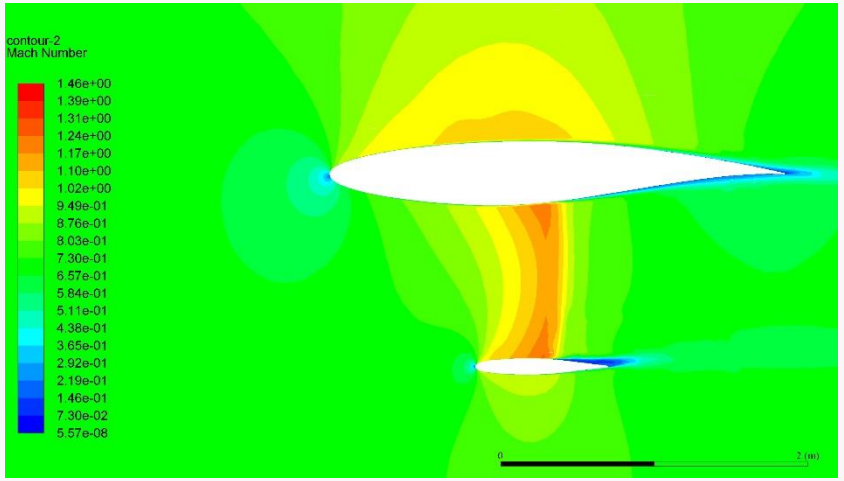




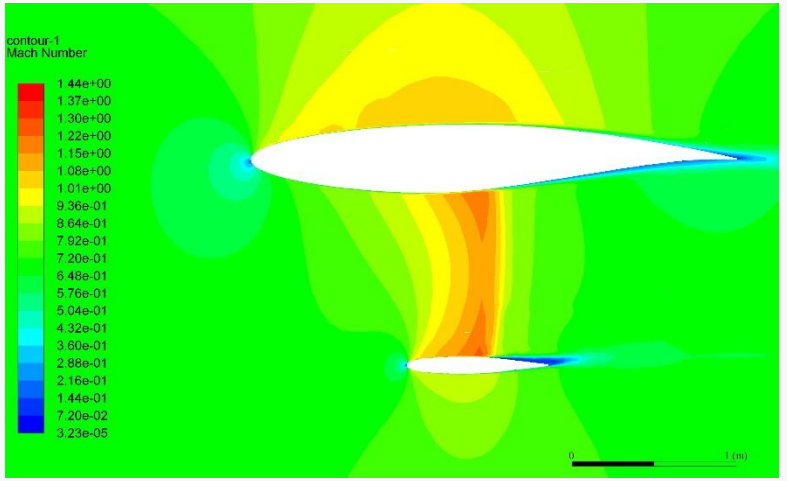


Results

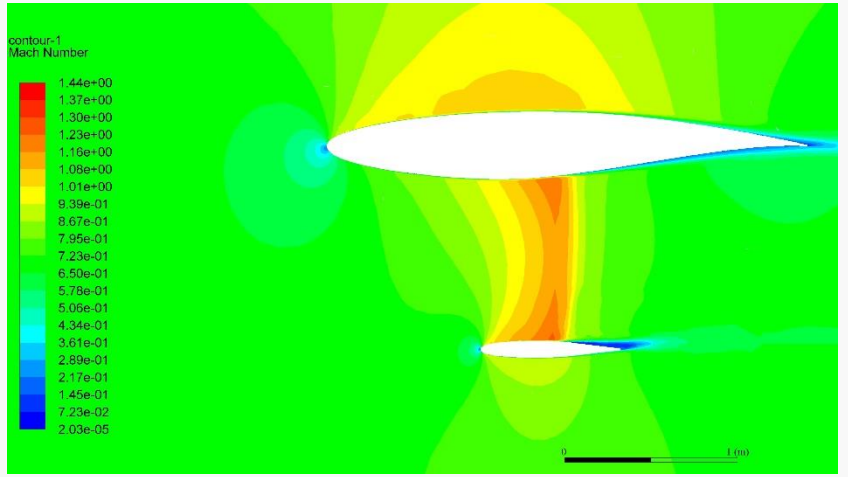
Baseline



KC-SCB_v0

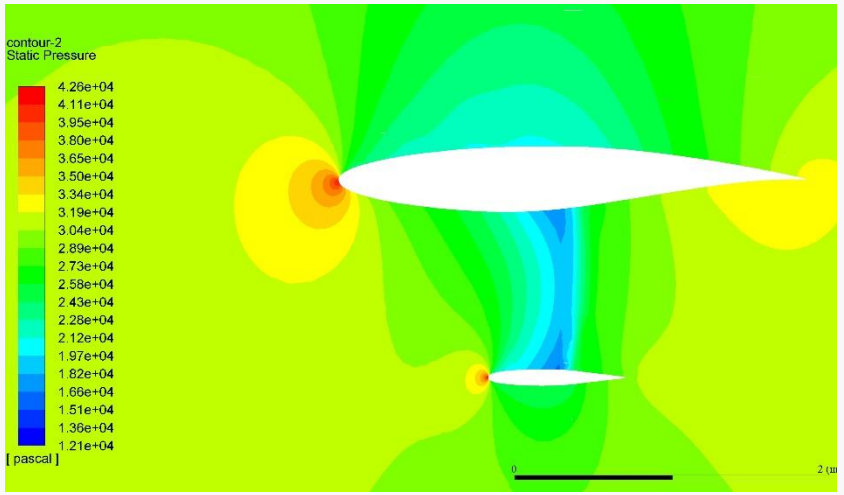


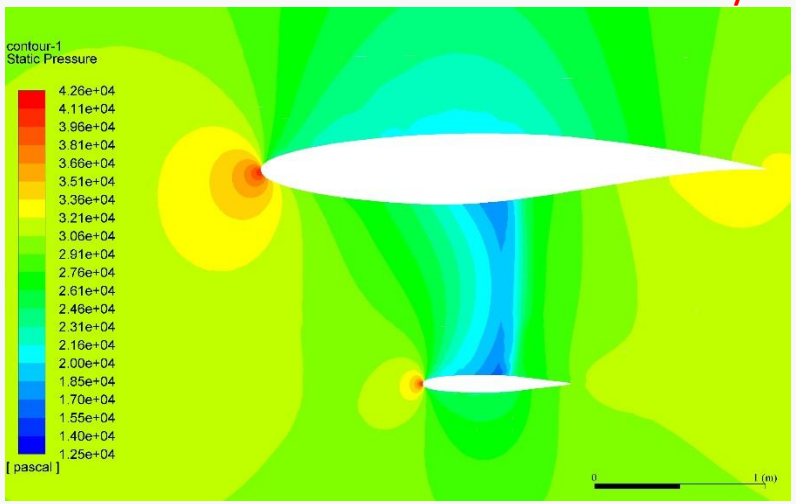
KC-SCB_v2

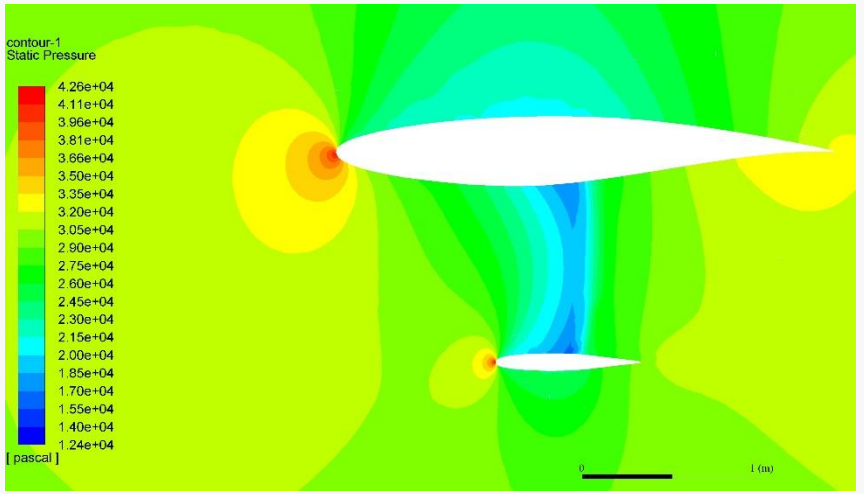


Y slice =13.5m

Little / No difference

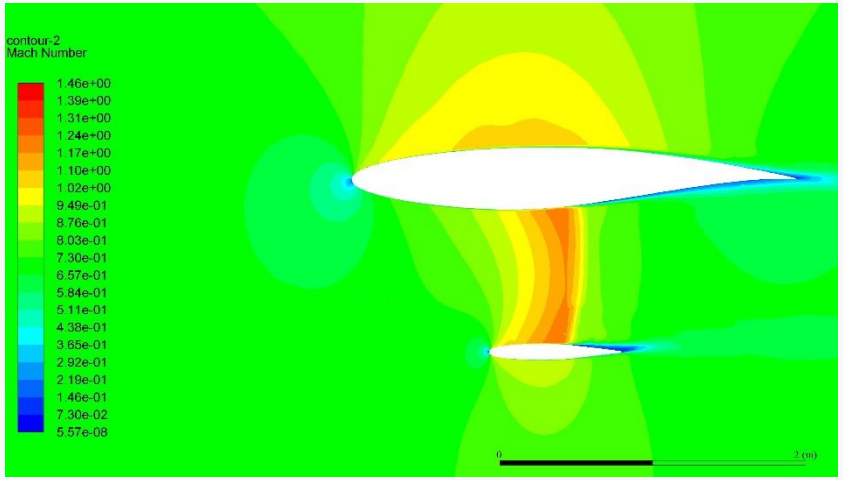




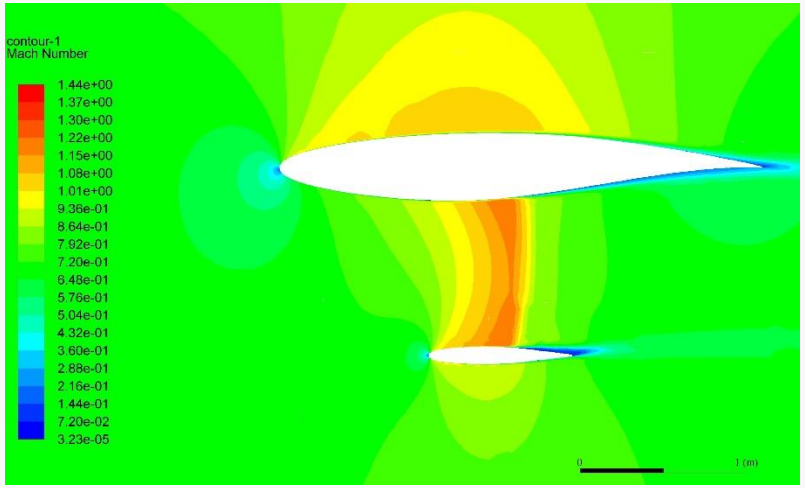


Results

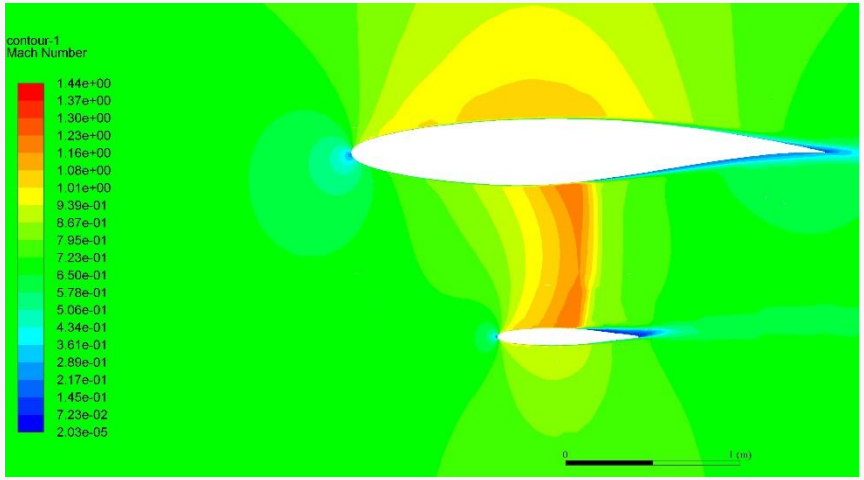
Baseline



KC-SCB_v0

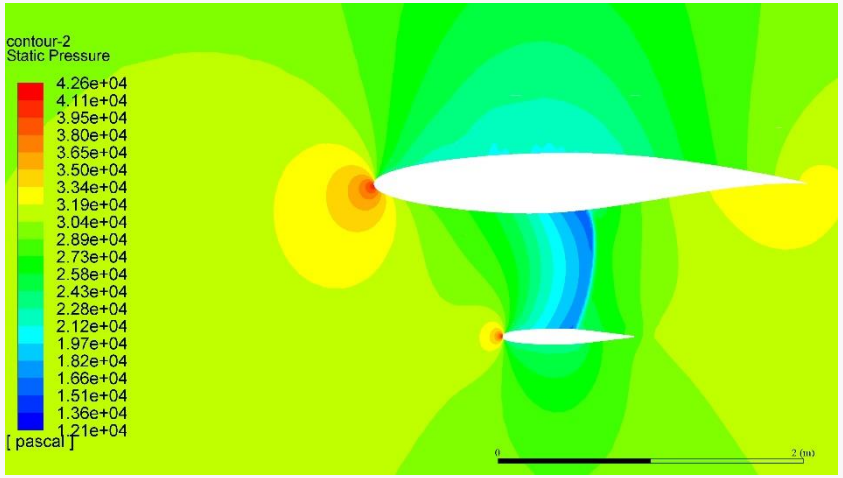


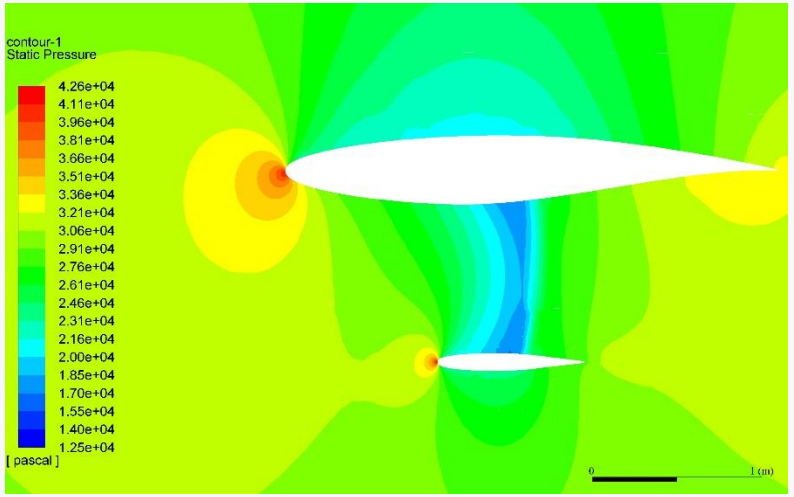
KC-SCB_v2

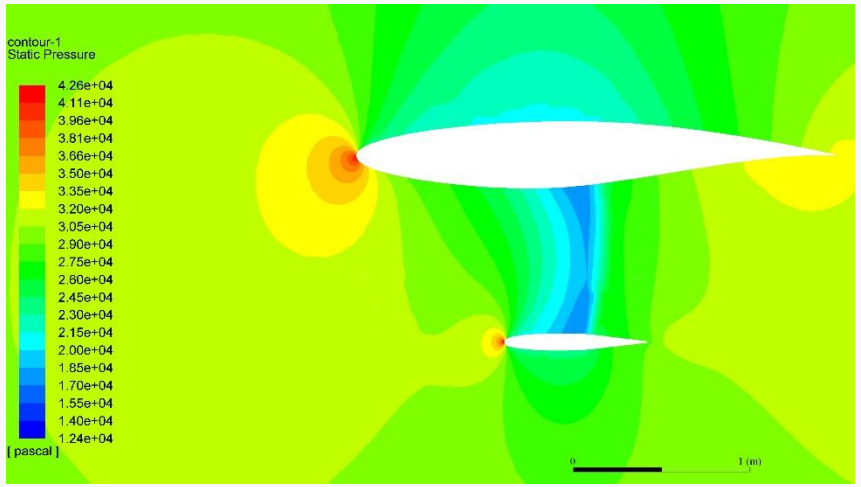


Y slice =14m

Little / No difference

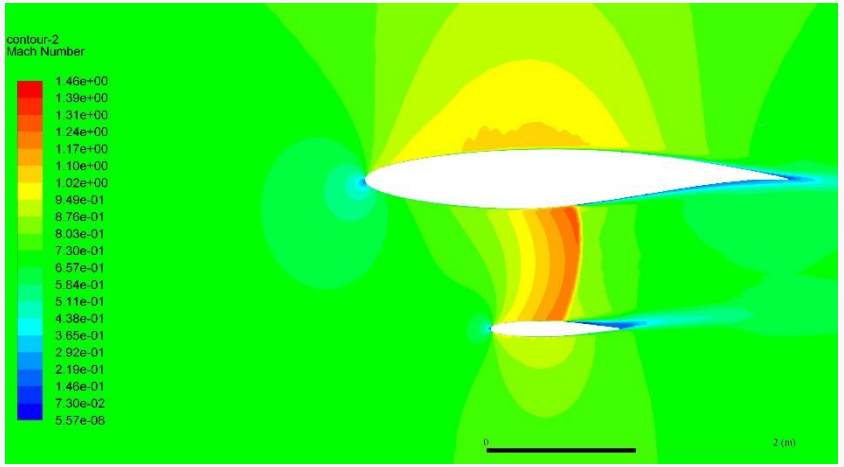




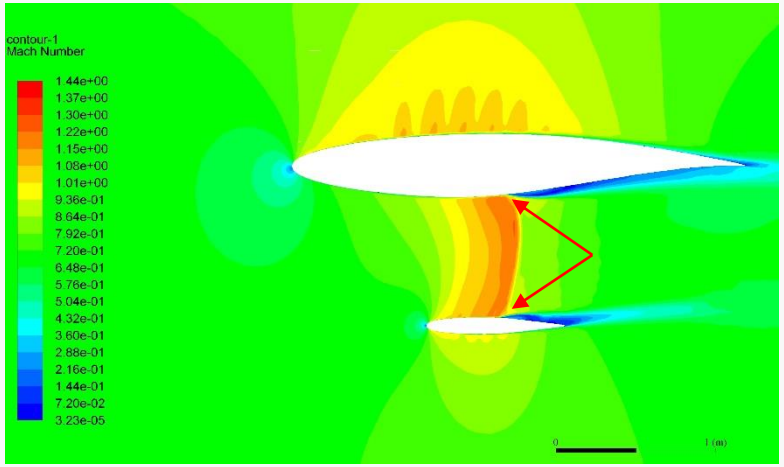


Results

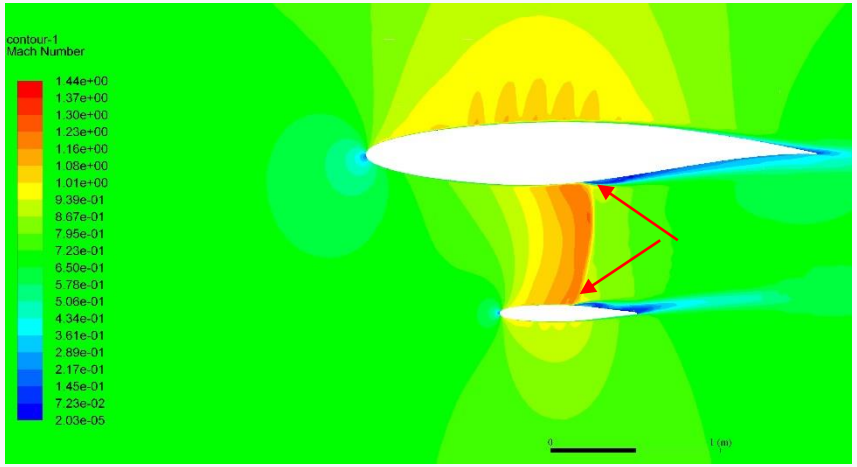
Baseline



KC-SCB_v0

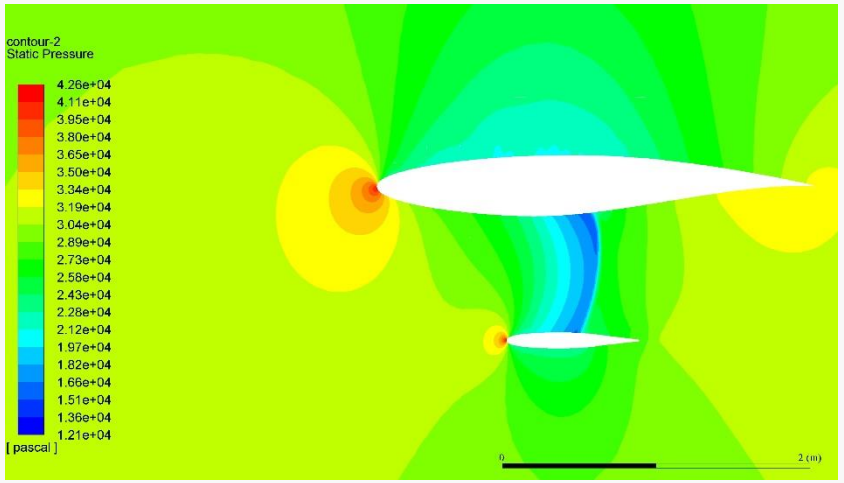


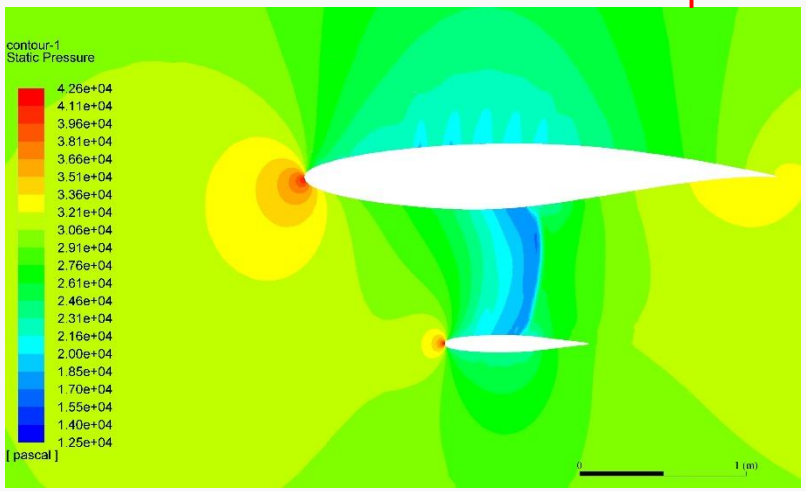
KC-SCB_v2

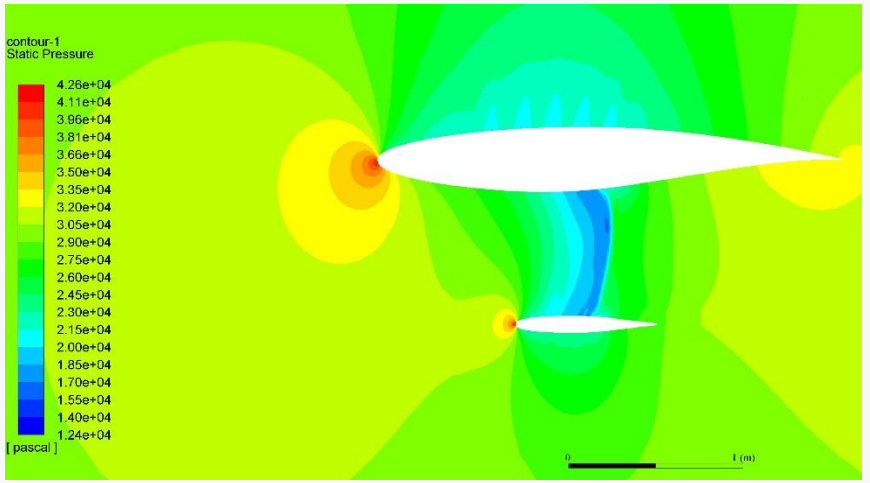


Y slice =14.5m

Separated flow

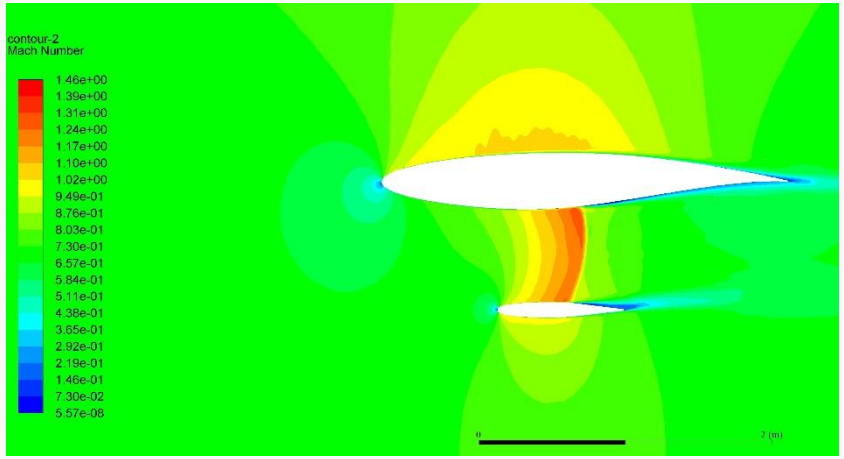




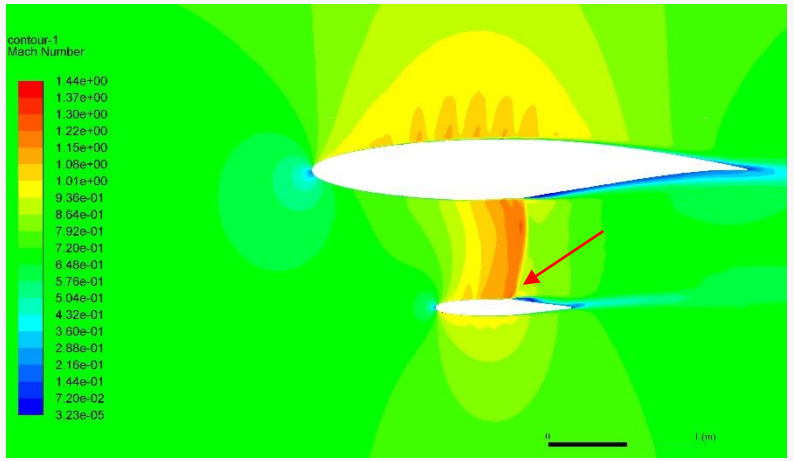


Results

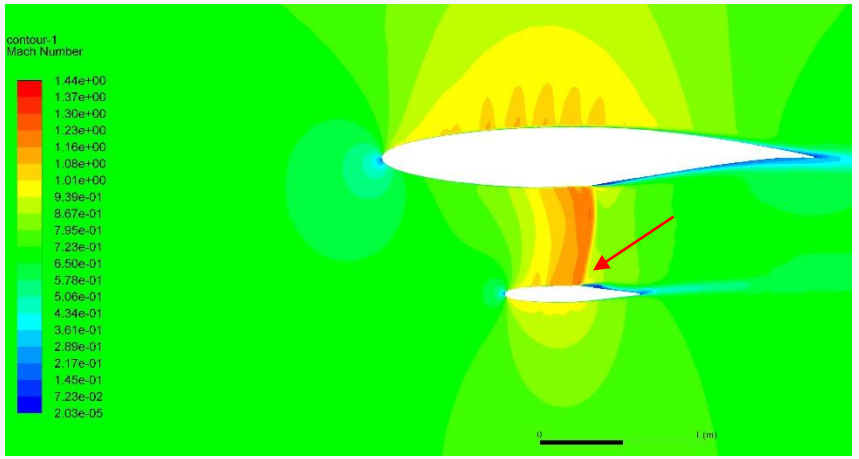
Baseline



KC-SCB_v0

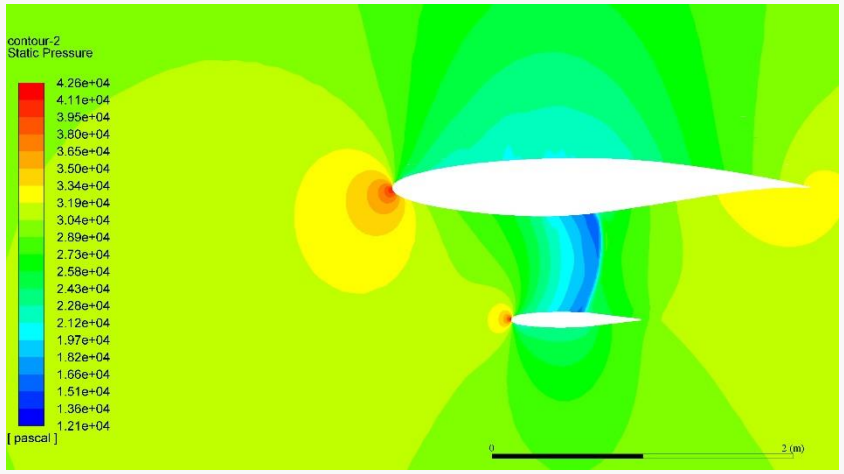


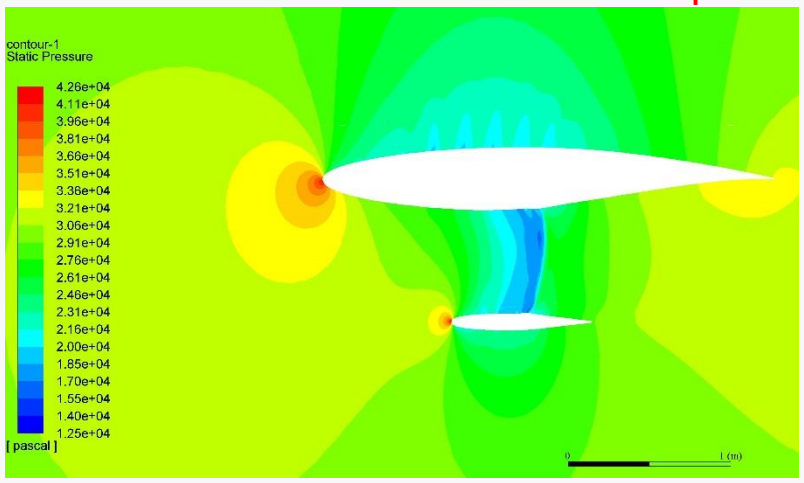
KC-SCB_v2

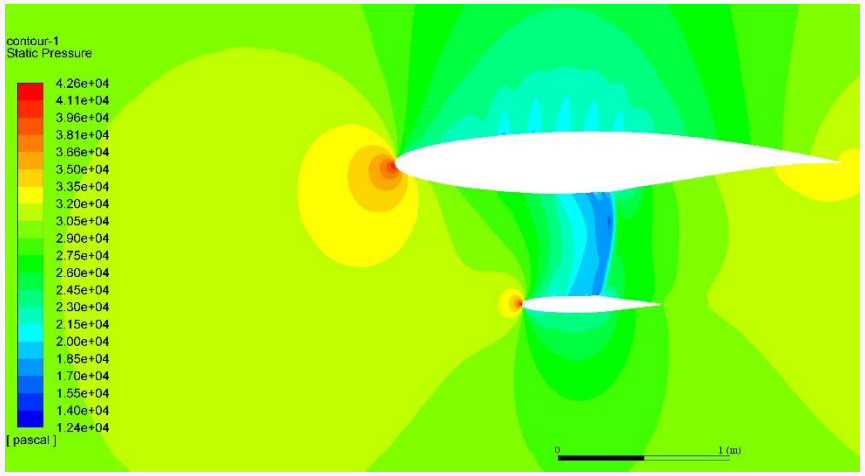


Y slice =15m

Separated flow

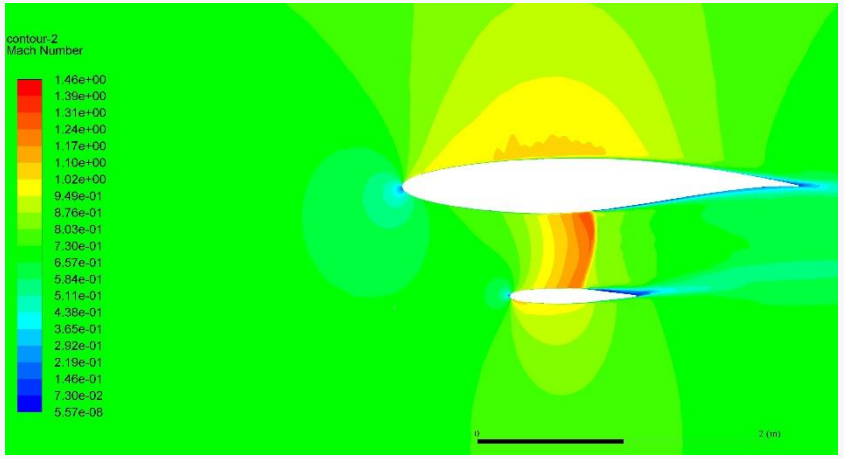




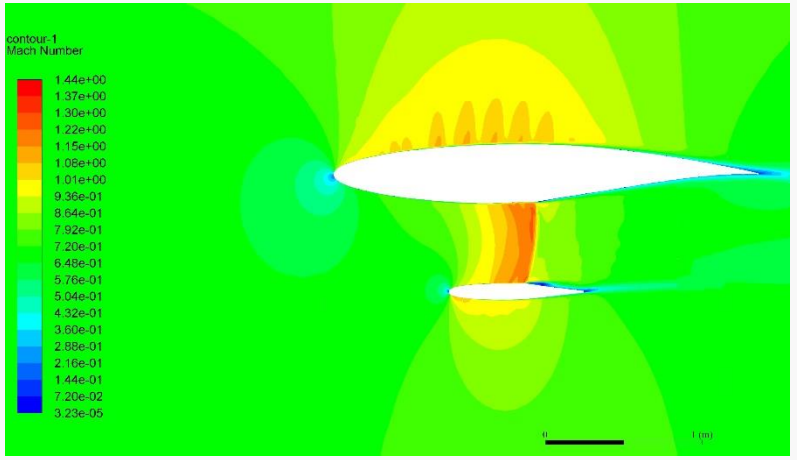


Results

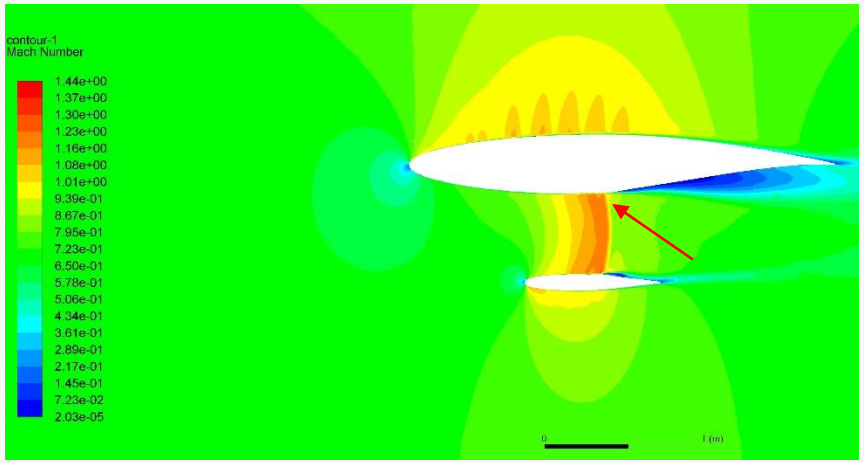
Baseline



KC-SCB_v0

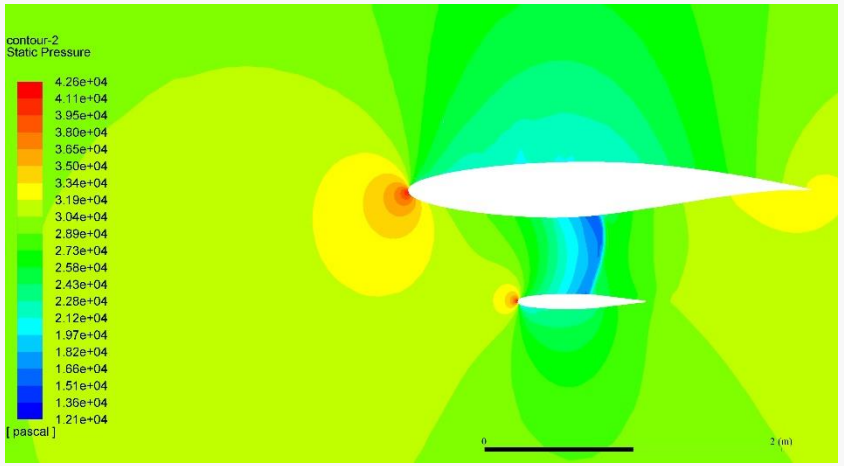


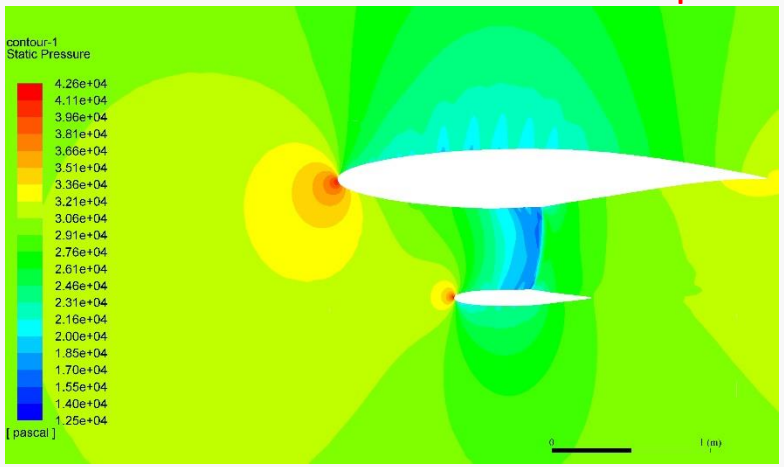
KC-SCB_v2

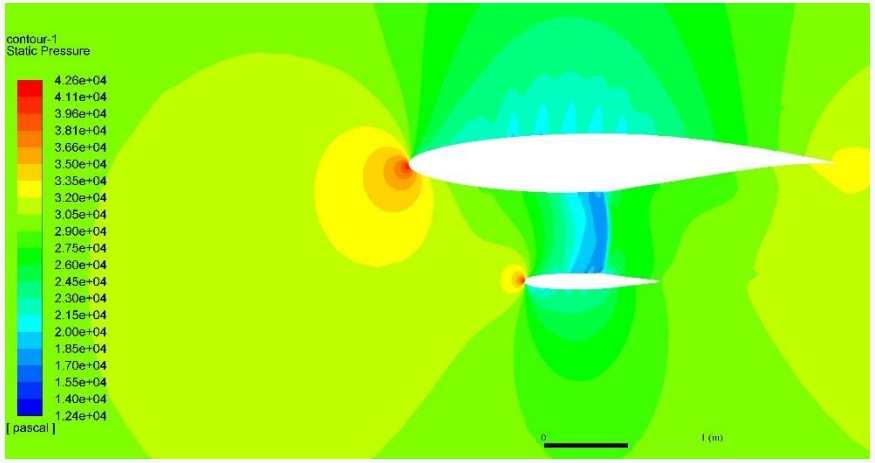


Y slice =15.5m

Separated flow

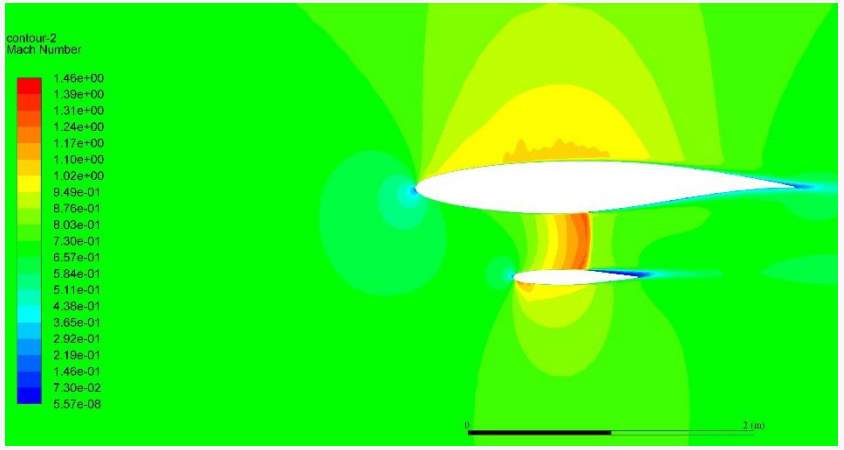




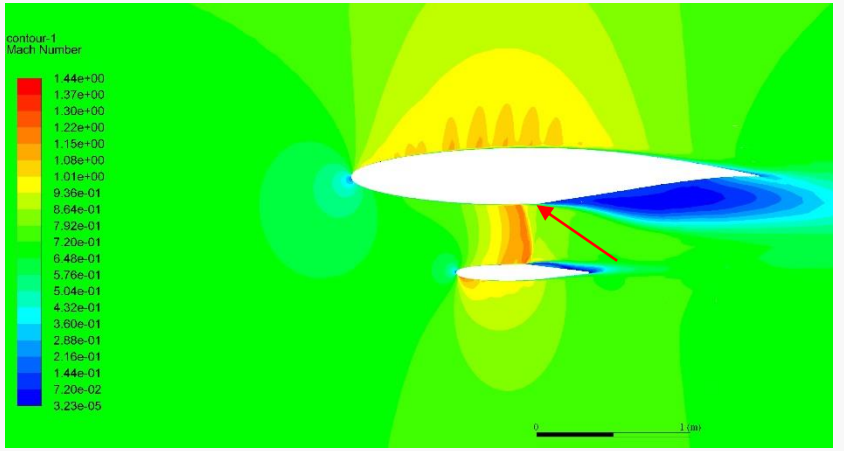


Results

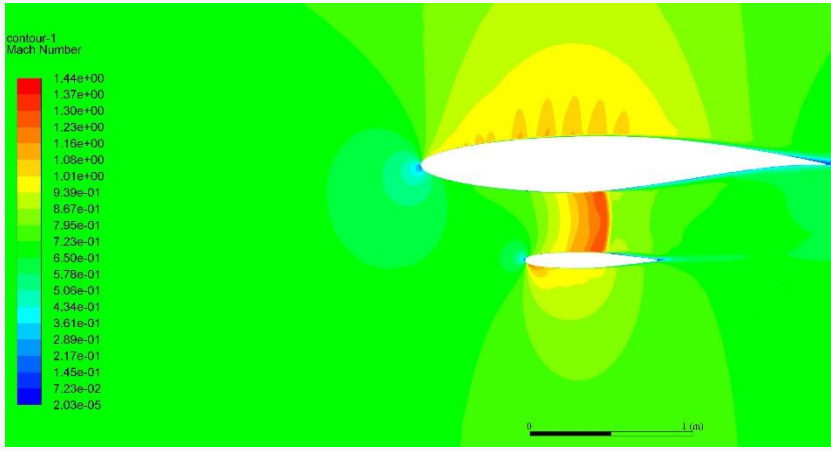
Baseline



KC-SCB_v0

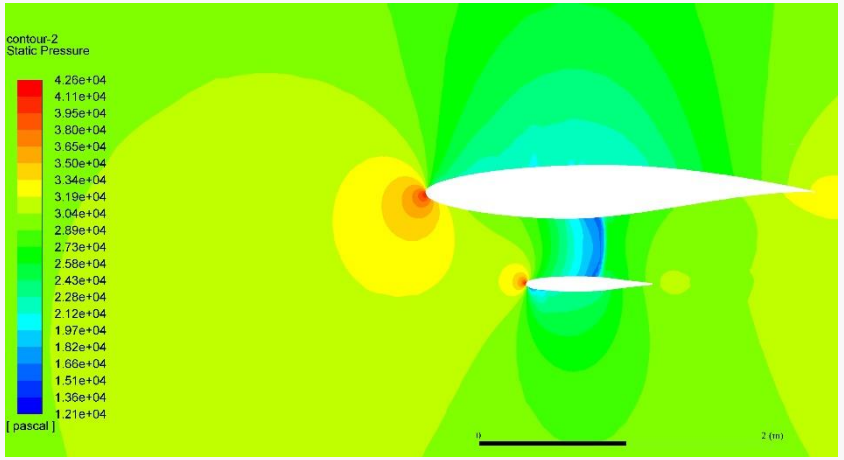


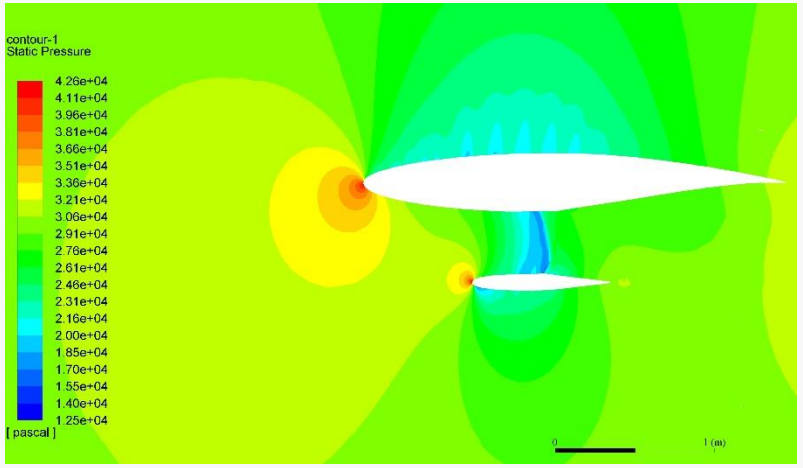
KC-SCB_v2

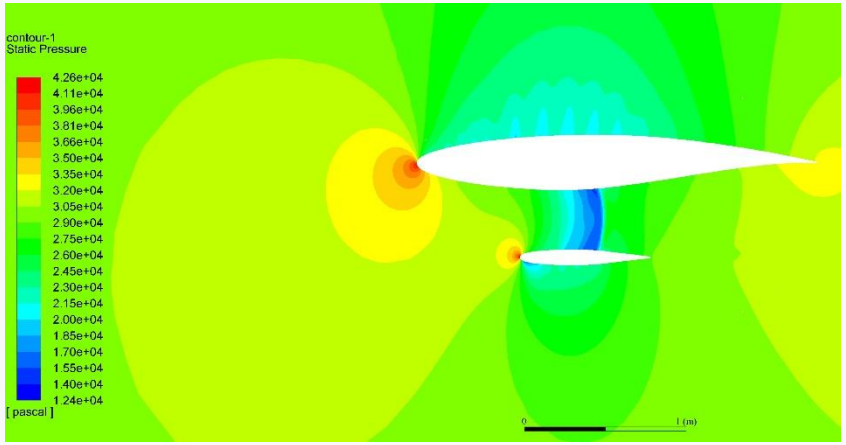


Y slice =16m

Separated flow

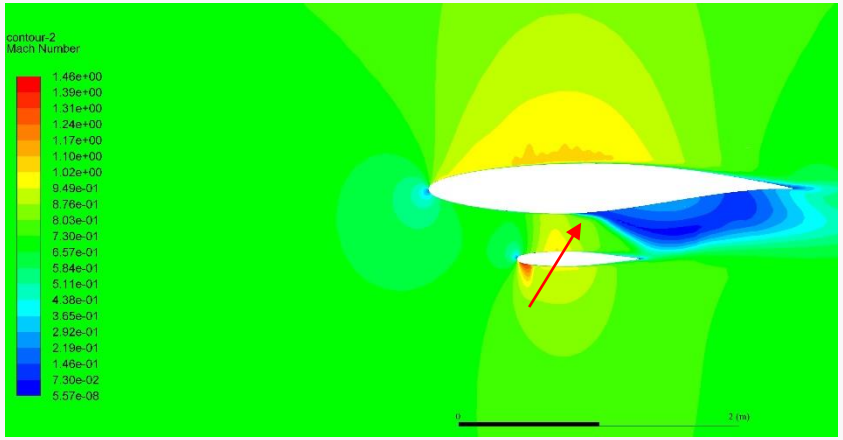




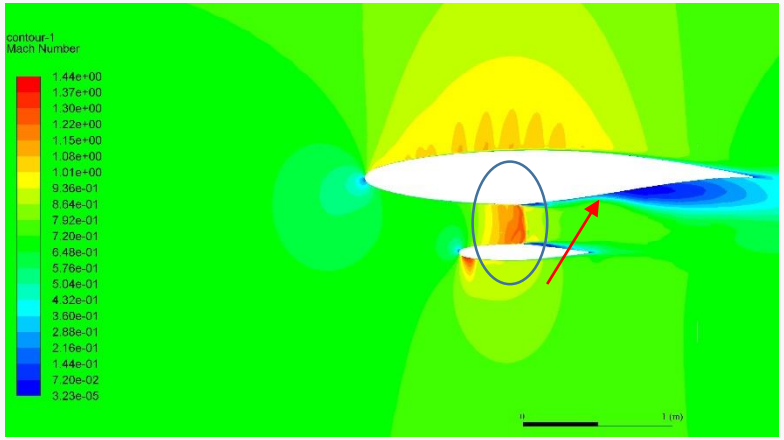


Results

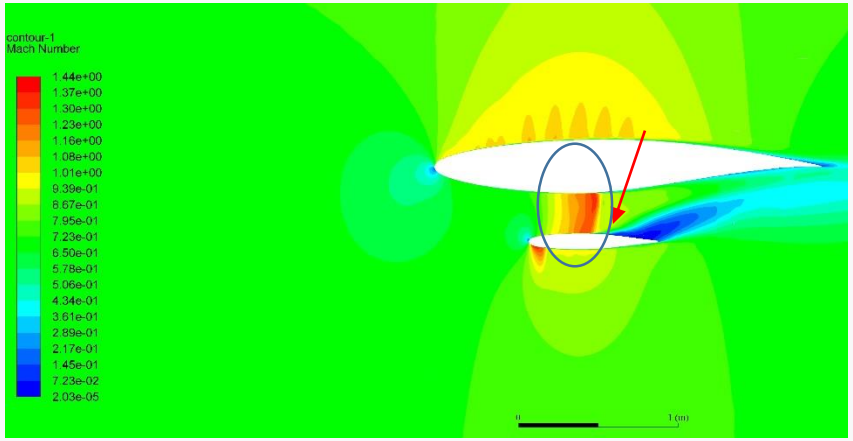
Baseline



KC-SCB_v0

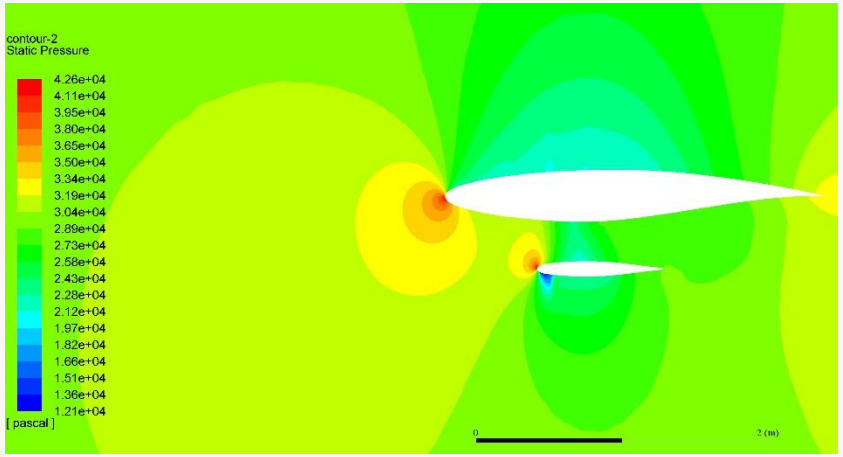


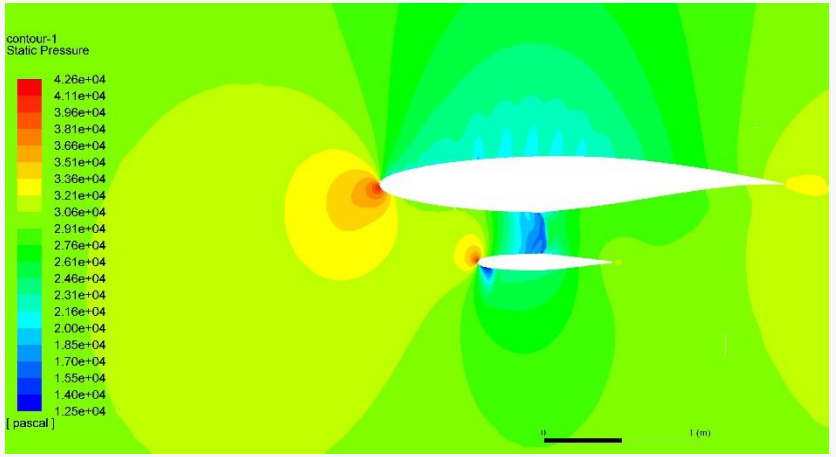
KC-SCB_v2

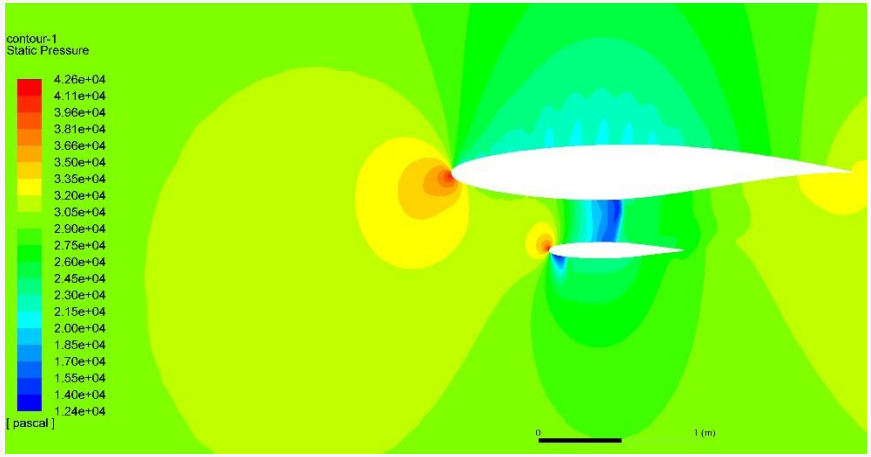


Y slice =16.5m

Separated flow and strong shock

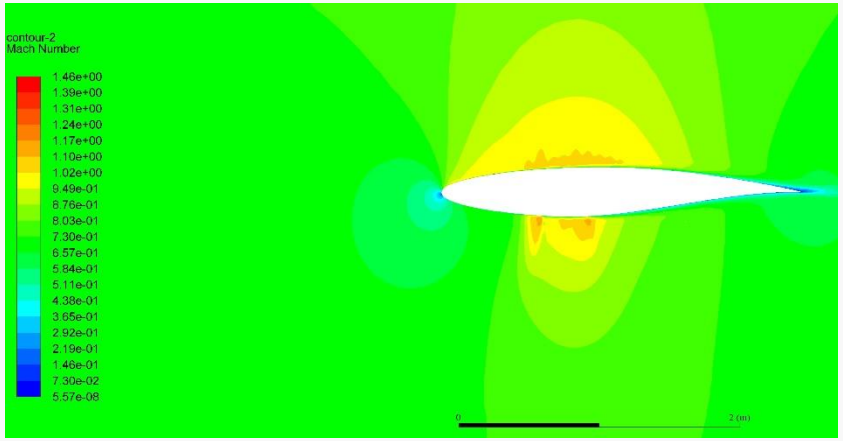




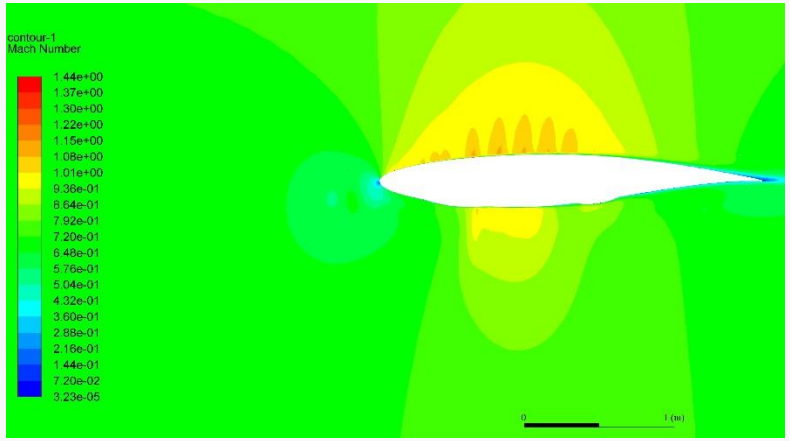


Results

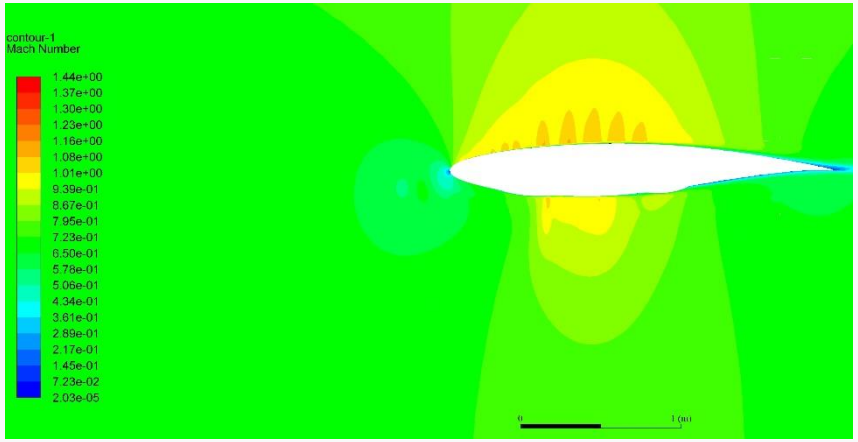
Baseline



KC-SCB_v0

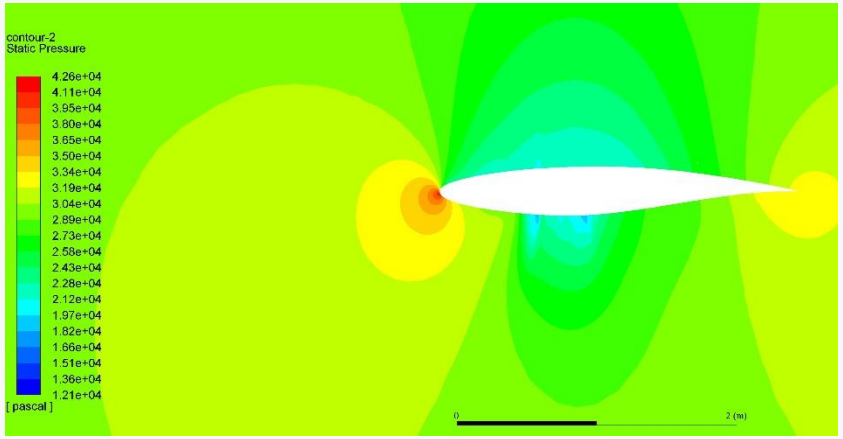


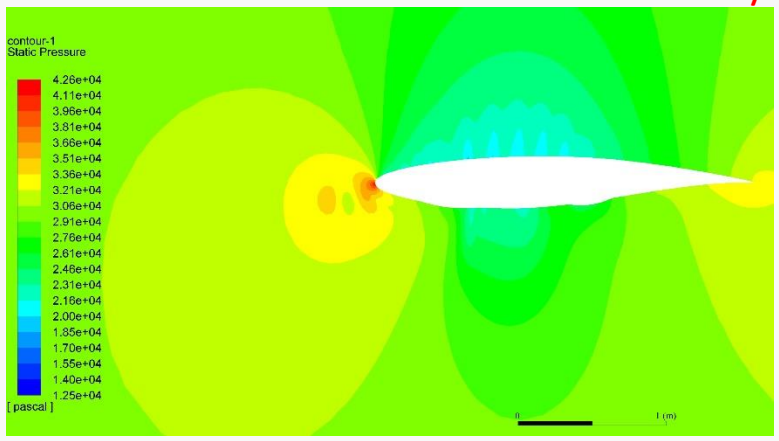
KC-SCB_v2

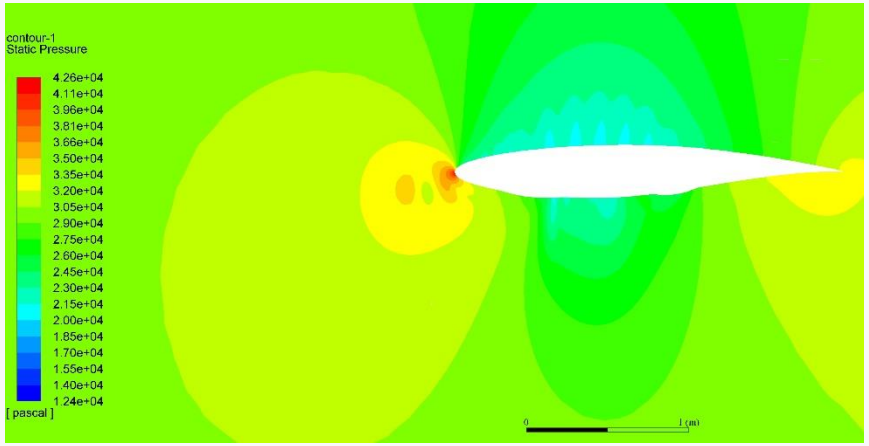


Y slice =16.8m

Little / No difference

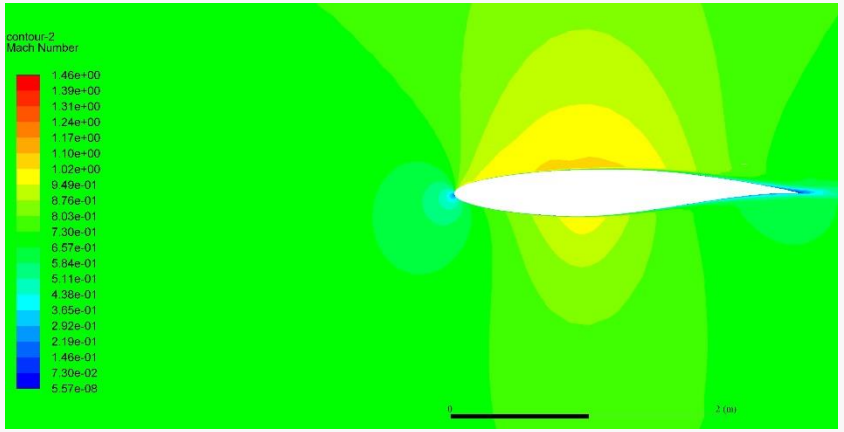




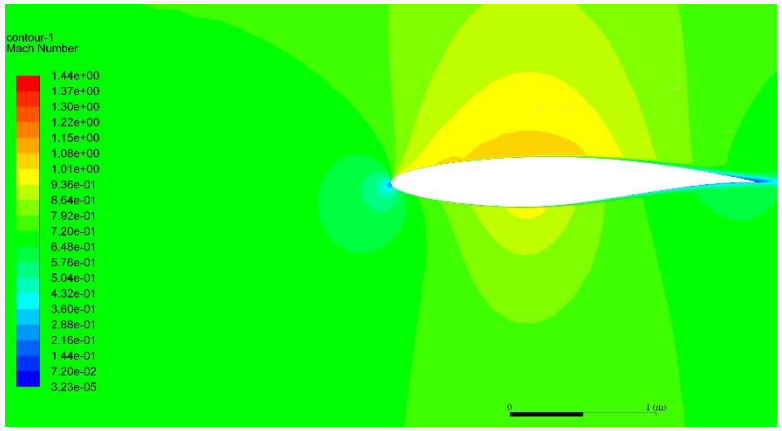


Results

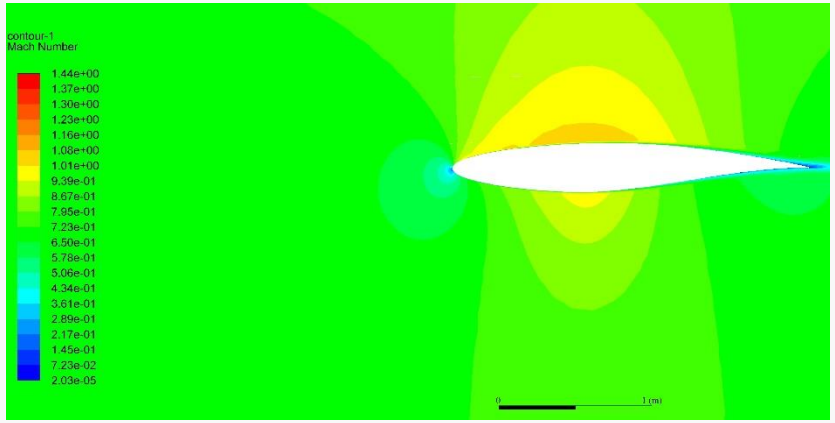
Baseline



KC-SCB_v0

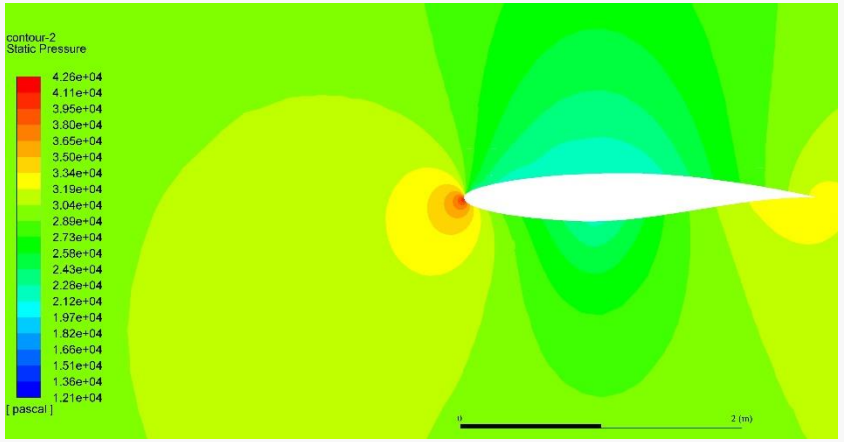


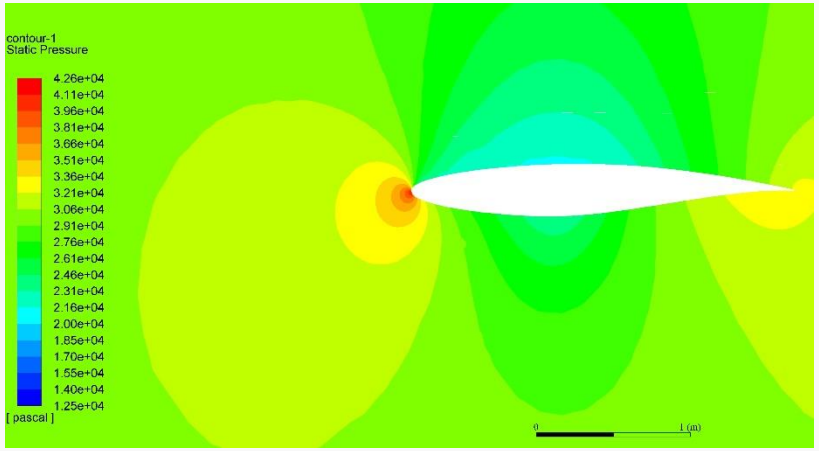
KC-SCB_v2

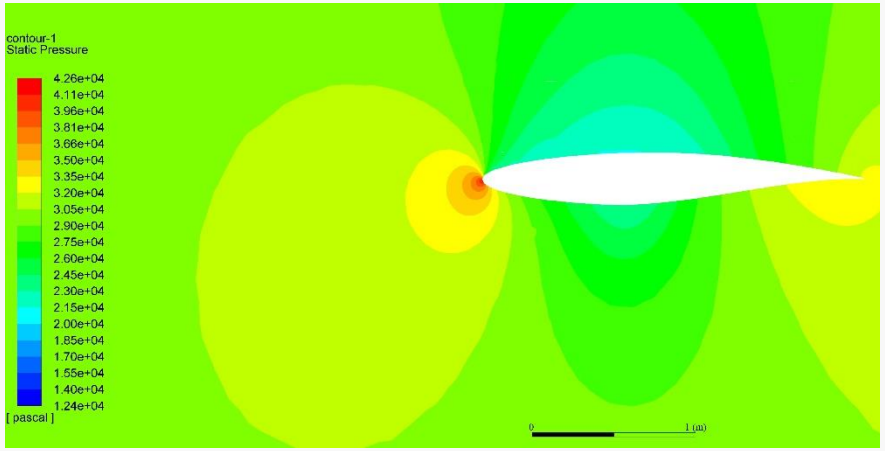


Y slice =17.3m

Little / No difference

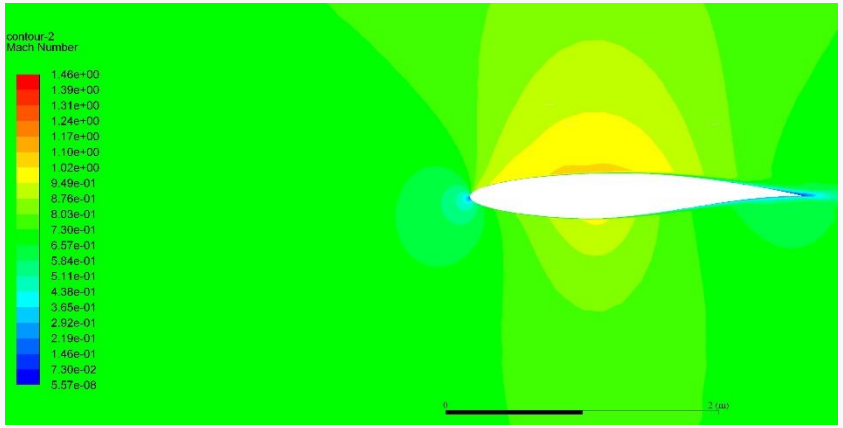




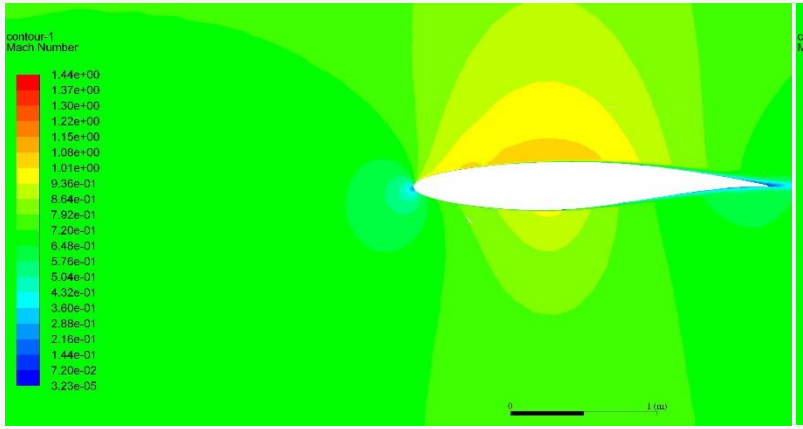


Results

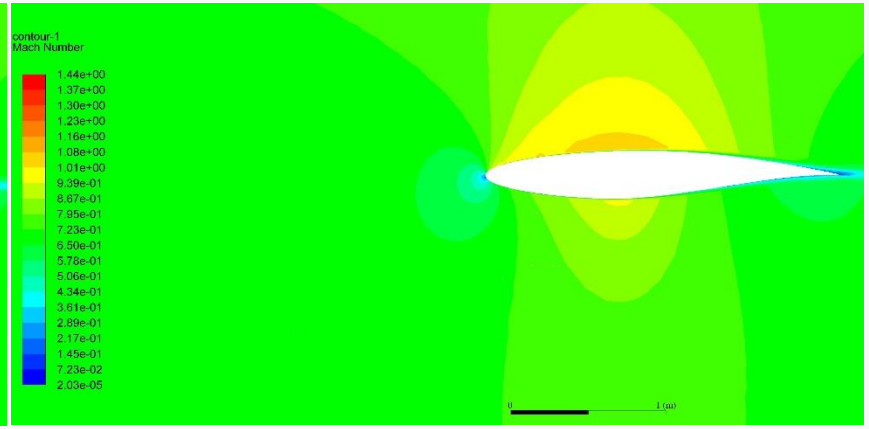
Baseline



KC-SCB_v0

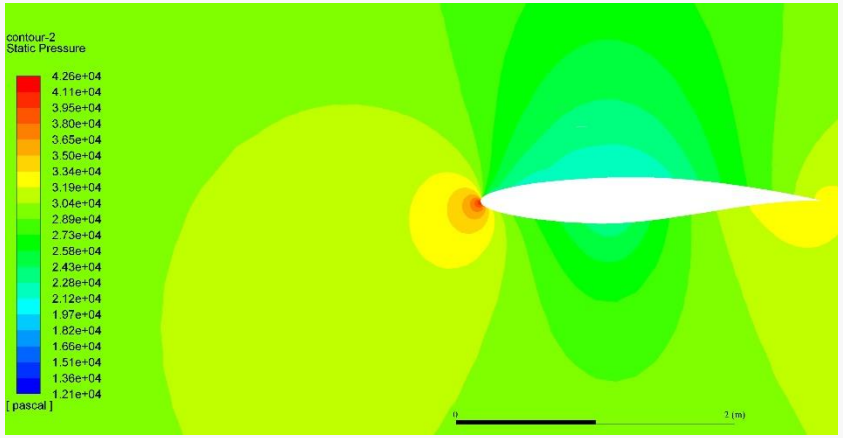


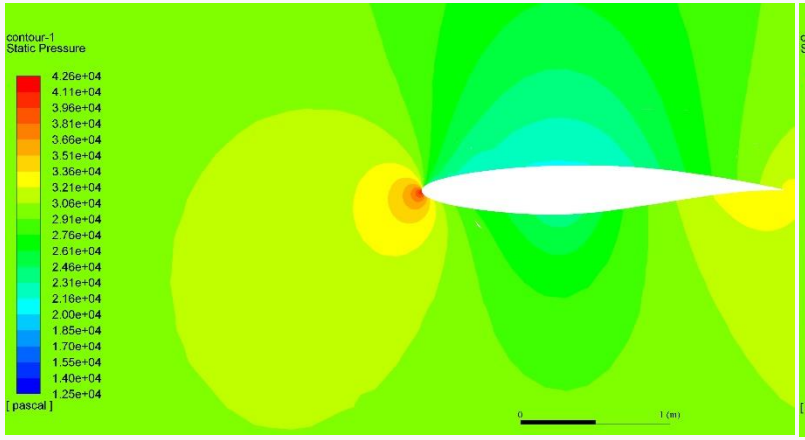
KC-SCB_v2

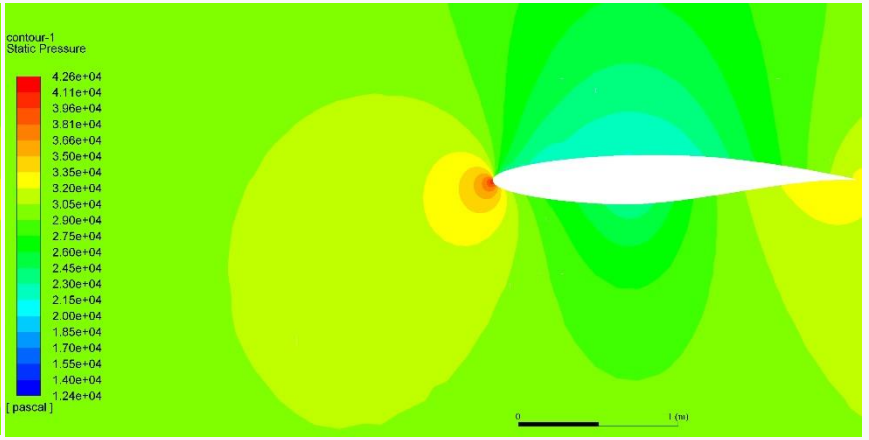


Y slice =17.8m

Little / No difference

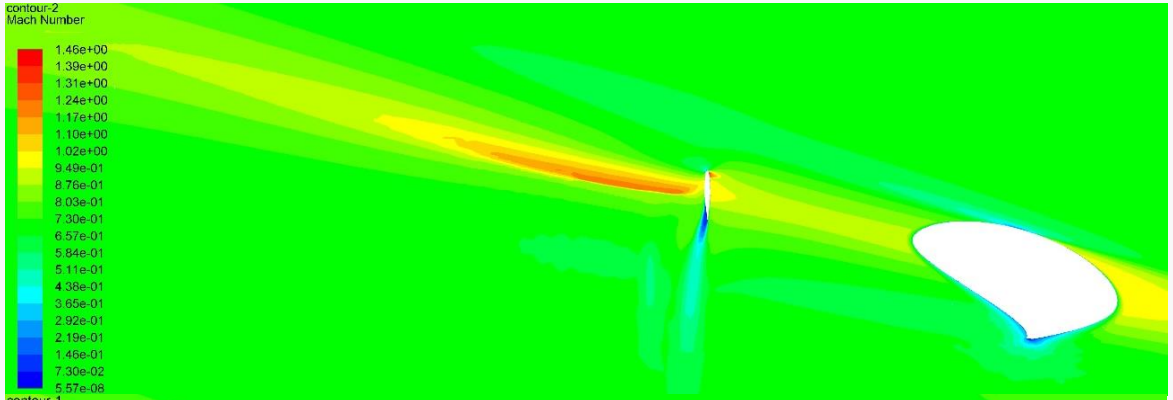




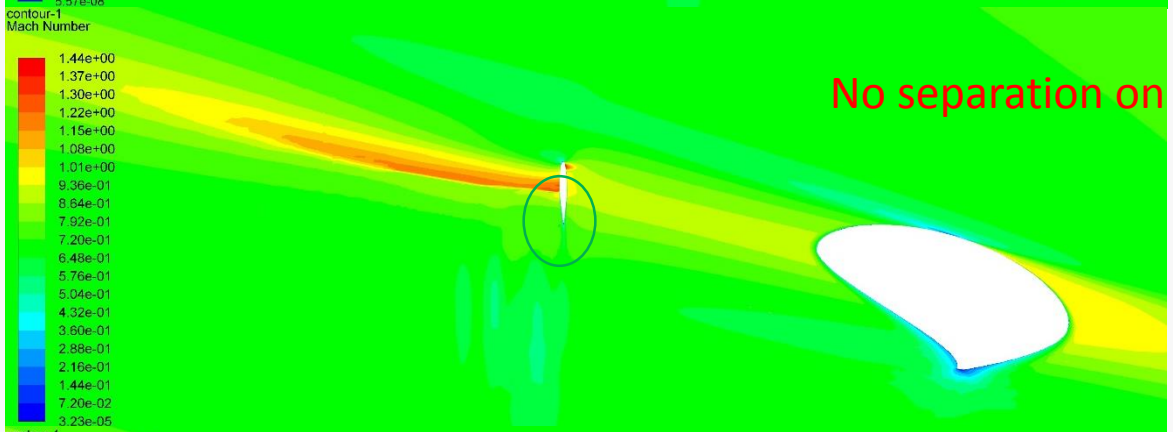


Results

Z slice =0.87m

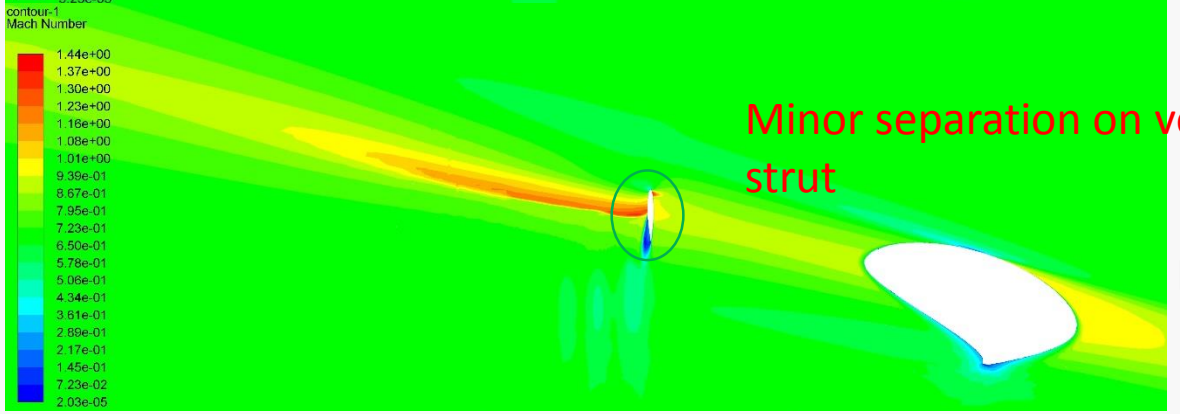


Baseline



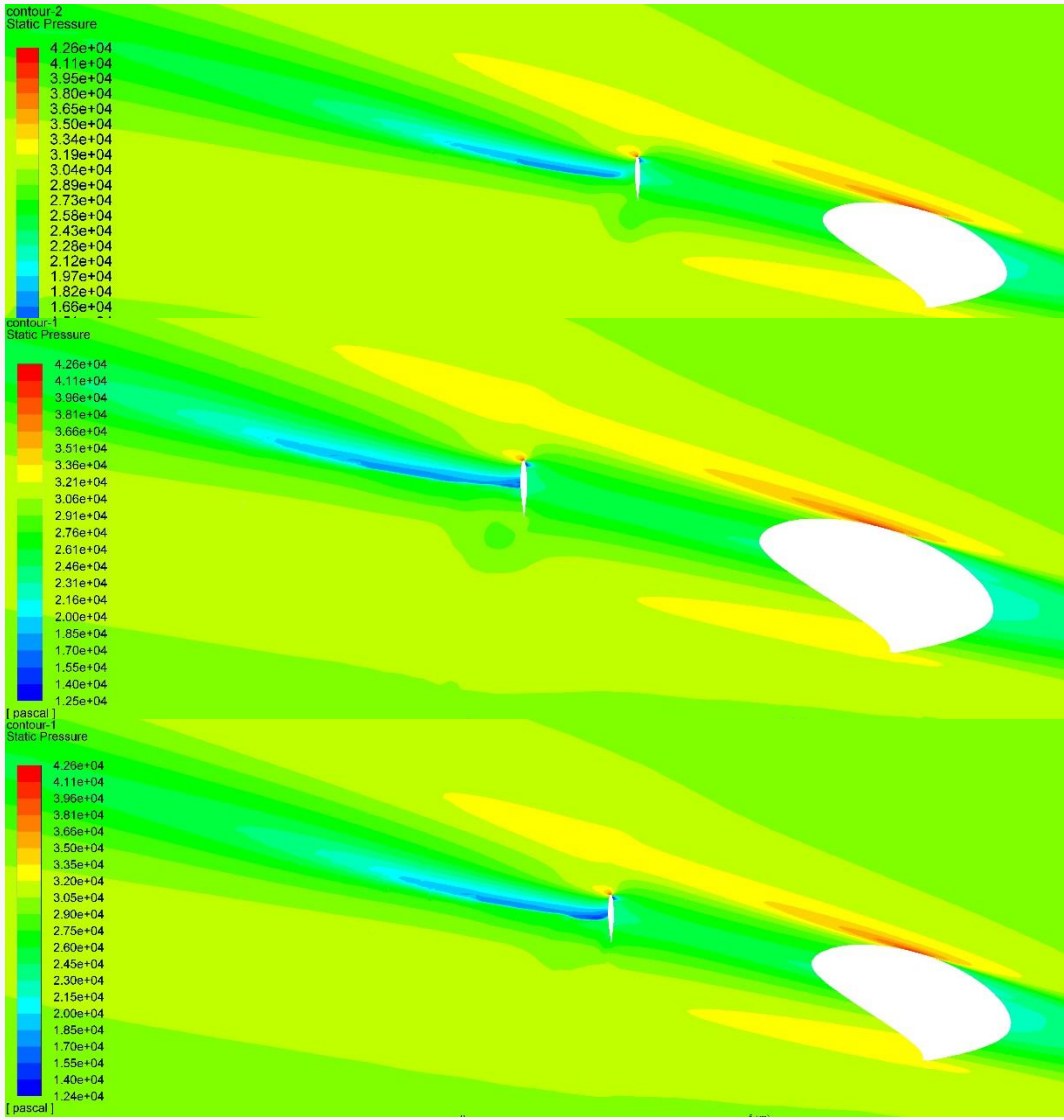
No separation on vertical strut

KC-SCB_v0

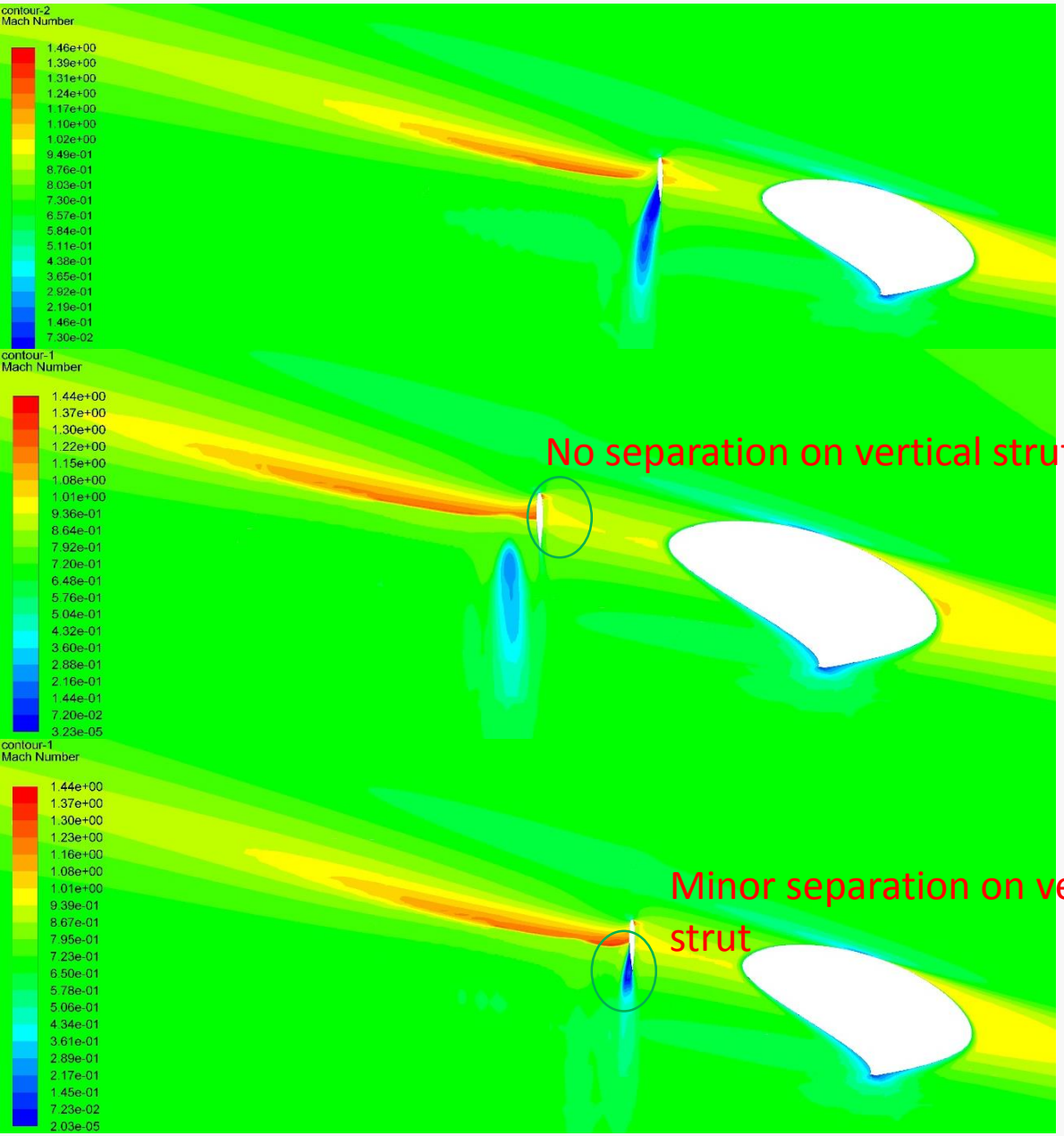


Minor separation on vertical strut

KC-SCB_v2



Results



Z slice =0.97m

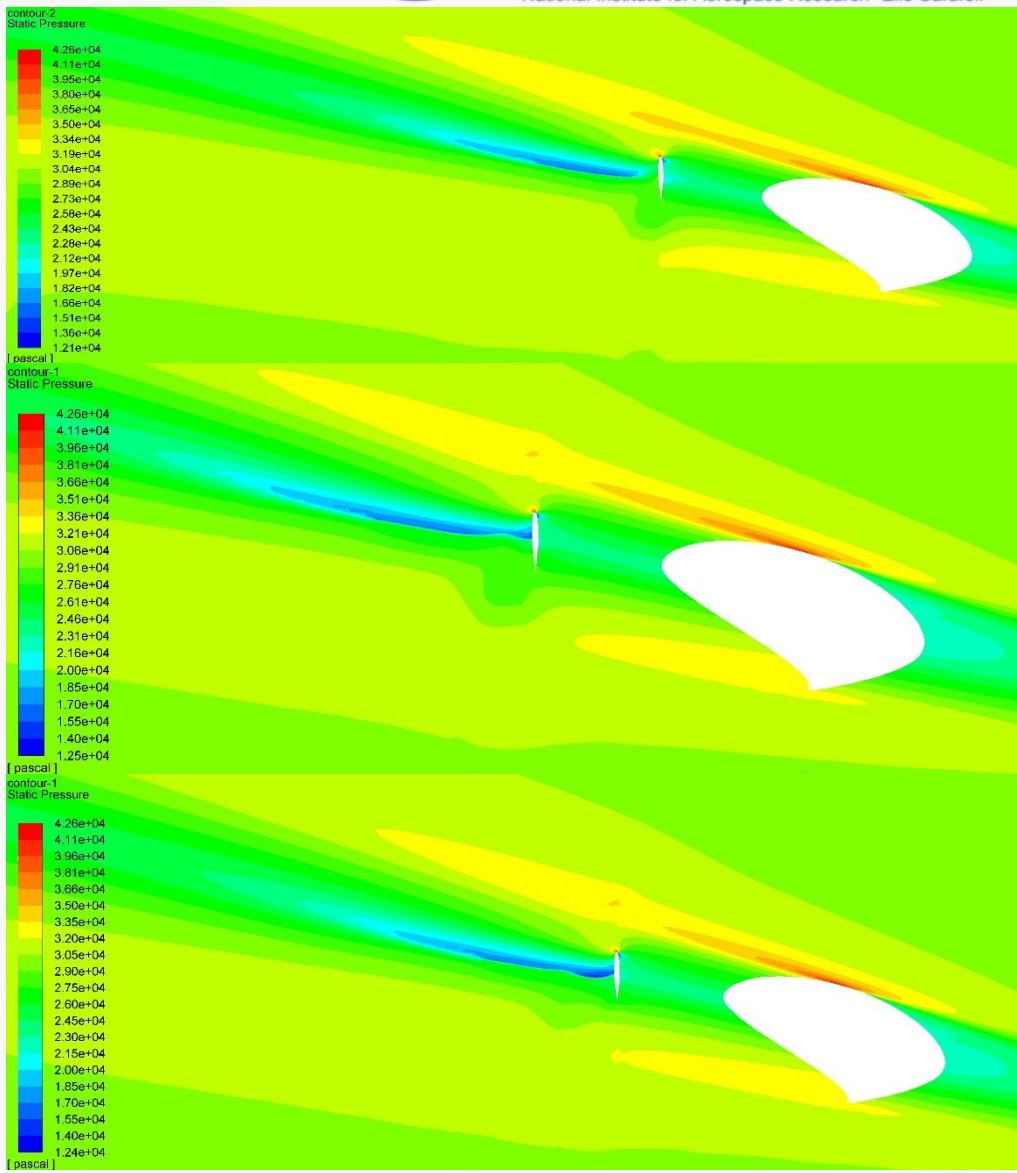
Baseline

No separation on vertical strut, but on the wing

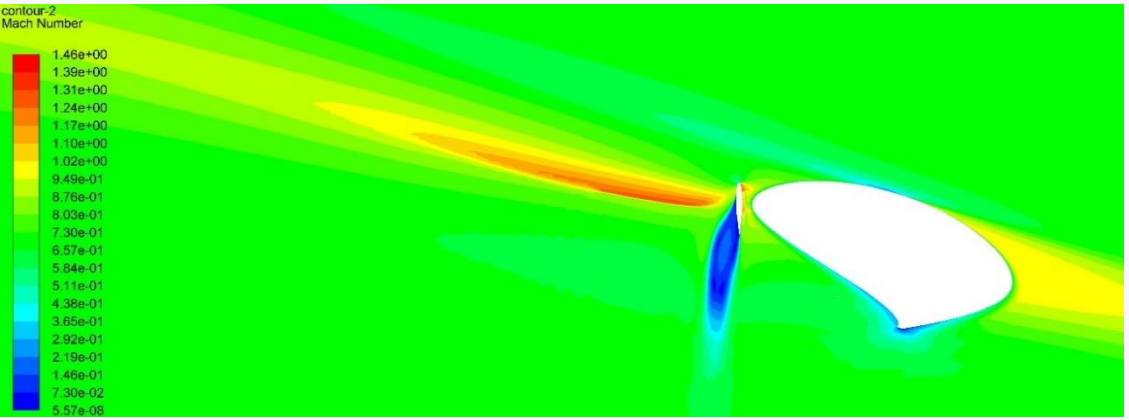
KC-SCB_v0

Minor separation on vertical strut

KC-SCB_v2

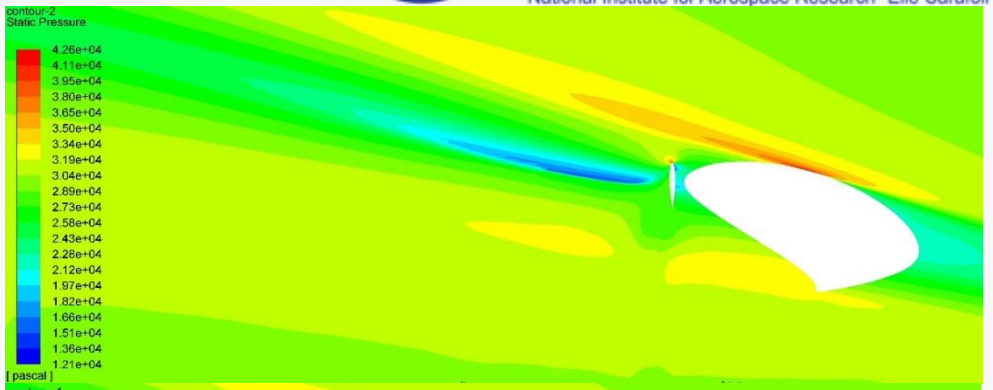


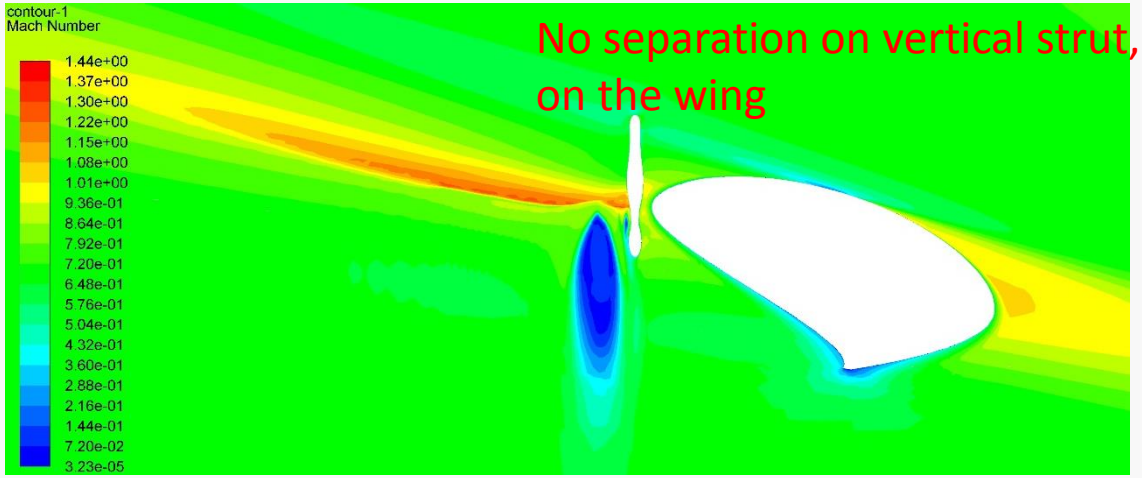
Results



Z slice =1.07m

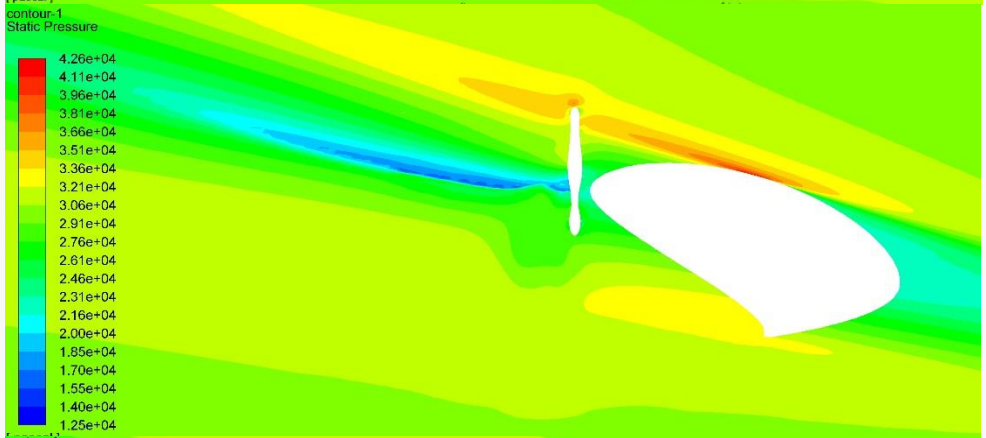
Baseline

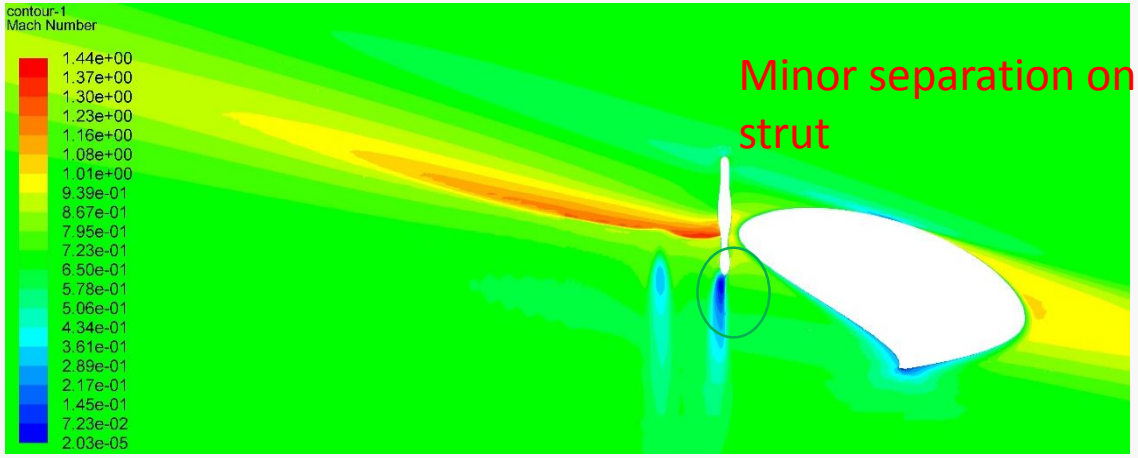




No separation on vertical strut, but massively on the wing

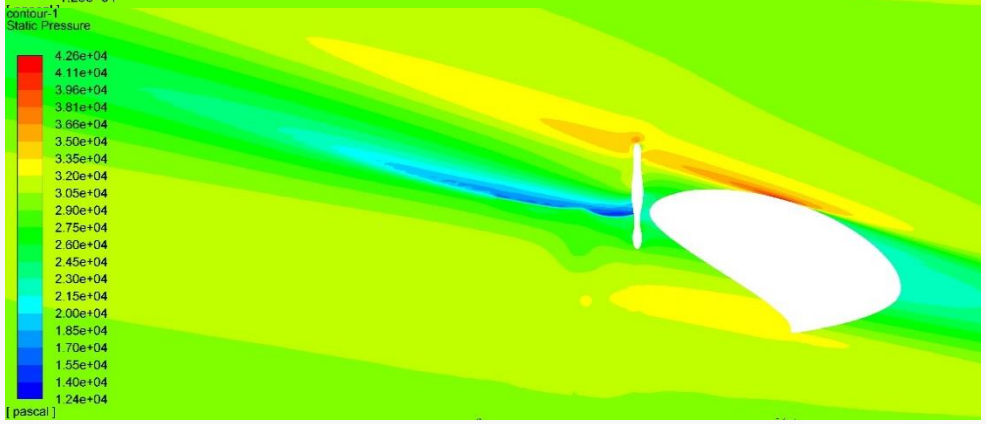
KC-SCB_v0





Minor separation on vertical strut

KC-SCB_v2



Conclusions

KC :

- Mitigates drag by locally controlling the flow at the wing strut junction
- Reduces flow separation on the wing, but induces on the strut--- to be improved!
- Improves flow also on the outer wing panel
- KC to be numerically optimized !

SCB :

- Mitigates drag by globally/span-wise controlling the flow
- To be verified a staggered arrangement on the wing/strut, or other formations
- SCBs to be numerically optimized in shape and orientation w.r.t. local flow direction!

KC-SCB:

- More work required, but there is “hope”!
- The trend is clear to reduce drag, just by “manually” improving the SCB number and position
- To be verified a staggered arrangement on the wing/strut, or other formations (?)
- SCBs to be numerically optimized in shape and orientation w.r.t. local flow direction!
- SCB close to the KC are aligned with the ideal flow direction not the local/KC induced one!

Thank you !

Questions ?